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Analysis of Low and Medium Rise Reinforced Concrete (RC) Buildings for Low Risk Earthquake Zone with Emphasis on Framed Structure

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Abstract
The majority of the Malaysian population do not associate Malaysia with earthquakes and seismic activity, hence, most of the reinforced concrete buildings had been designed in accordance to the previous British code of practice BS 8110, which has been phased out in UK since 2010. In Malaysia now, all RC building structures are to be designed to Eurocode 2 or EN1992. Although Malaysia is not located within any active seismic fault zone, some parts of the country do experience far-field earthquake effects from Sumatra Island, East of Indonesia. After having experienced the 2004 Aceh earthquake where some highrise building structures swayed substantially, the public raised some concerns about the integrity of the existing highrise buildings in Peninsular Malaysia to resist far-field earthquake tremors. In addition to Eurocode 2, Malaysia has also released the National Annex to Eurocode 8 or NA to MS EN1998, which is the European standards for seismic design now been adopted by Malaysia. Hence, the cost of construction according to seismic design may have a major economical impact on the Malaysia's local construction industry. In the interest of public safety and awareness, this research develops a detailed structural performance evaluation for typical RC low and medium rise buildings in Malaysia. At the same time, the difference in material resource usage between seismic design and non-seismic design is investigated. It is observed that the inter-storey drift ratio and the weight of steel reinforcement used in design is strongly influenced by the intensity of peak ground acceleration, a_{gR} and the corresponding structural behaviour factor, q.

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Introduction

Earthquakes are one of the most devastating and unpredictable natural hazards which cause great loss of life and livelihood (Elnashai, 2008).Although Malaysia is located in the stable Sunda Shelf with low to medium seismic activity level, the seismic risk cannot be ignored (Manafizad, Pradhan and Abdullahi, 2016). It is

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inevitable to give considerable attention to the reactivation phenomenon of inactive faults, especially within the vicinity of 80km-long Bentong Fault. The epicenters were as close as 20 km to high population Kuala Lumpur, which a slight higher value of magnitude could have remarkable effects on seismic hazard of the region. In fact, historically, these earthquakes happened in rural area with low population and have not yet inflicted any serious damage of buildings. However, due to the series of local origin earthquakes and increased of population in the rural area, government has urged the engineers to factor earthquake in development projects, especially for those on fault lines. The fact that, majority of the existing low- to mid-rise buildings in Malaysia including residential houses, schools, government offices and hospitals are suspected to have higher risk of collapsing compare to high-rise buildings. Since reinforced concrete (RC) requires less skilled labor and low maintenance cost, majority of these buildings are RC structures typically designed without provisions for earthquake-induced forces and are considered as weak to seismic loads.In the interest of public safety, this research develops a detailed structural performance evaluation for typical RC low and medium rise buildings in Malaysia. This paper also investigate the difference of steel reinforcement and concrete required when seismic provision is considered in reinforced concrete (RC) design of general hotel building.

Problem Statement

Although Malaysia is located in the stable Sunda Shelf with low to medium seismic activity level, the seismic risk cannot be ignored (Manafizad, Pradhan and Abdullahi, 2016).It is inevitable to give considerable attention to the reactivation phenomenon of inactive faults, especially within the vicinity of 80km-long Bentong Fault. The epicenters were as close as 20 km to high population Kuala Lumpur, which a slight higher value of magnitude could have remarkable effects on seismic hazard of the region. In fact, historically, these earthquakes happened in rural area with low population and have not yet inflicted any serious damage of buildings. However, due to the series of local origin earthquakes and increased of population in the rural area, government has urged the engineers to factor earthquake in development projects, especially for those on fault lines. The fact that, majority of the existing low- to mid-rise buildings in Malaysia including residential houses, schools, government offices and hospitals are suspected to have higher risk of collapsing compare to high-rise buildings. Since reinforced concrete (RC) requires less skilled labour and low maintenance cost,majority of these buildings are RC structures typically designed without provisions for earthquake-induced forces and are considered as weak to seismic loads.

Literature Review

European Code and National Annex Studies

Malaysia has adopted Eurocode (EN 1998-1) in the seismic design of reinforced concrete structures. The first edition of Malaysia National Annex to MS EN1998 Part 1: Design of Structures for Earthquake Resistance was drafted in 2017. Seismic hazard modelling of the region surrounding Malaysia with the methods mentioned in the previous chapters had been researched by the members in the authorship in order to produce the seismic hazard map and elastic model response spectrum for Peninsular Malaysia, Sarawak and Sabah (Lam, 2018). The key points from Eurocode 8 and Malaysia National Annex were studied in order to perform the analysis and design in this research.

Current Eurocode Provisions

Two fundamental requirements in seismic design is established in EN1998-1, which are as follows:

a) No-collapse requirement (Ultimate Limit State)
   In this requirement, it stated that for ordinary structures should be constructed and designed for a reference seismic action with 10% probability of exceedance in 50 years (475 year return period). In this case, this ensure that the building is able to withstand the design seismic action without local or global collapse as the it is subjected a rare

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seismic event that can caused significant event.

b) Damage limitation requirement (Serviceability Limit State)
The requirement is to ensure that the building is designed to withstand a more frequent seismic action without damage. The limitation is related to the reduction of economic losses in terms of structural and non-structural in frequent earthquakes. No permanent deformation is alow to occur on the structure.

Hence, the two level seismic design requirements are actually depending on the probability of occurrence of the earthquake (JRC European Commission, 2012).

Seismic Parameters Studies Based on Eurocode 8 and Malaysian National Annex to Eurocode 8

In order to perform a detailed study and evaluation on the seismic performance of the low rise building, it is important to define the following seismic parameters based on the seismic code and National Annex of the respective country. The parameters are as follows:

1) Reference Peak Ground Acceleration
2) Building Importance factor
3) Behaviour Factor
4) Site Natural Period & Response Spectrum

Site Natural Period & Response Spectrum

In this study, only horizontal elastic response spectrum was considered in the analysis. The response spectrum was obtained by modal analysis. However, before proceeding to the analysis, several steps have to be taken in order to obtain the input parameters for the construction of soil response spectrum:

1) Obtain the Borehole report of the proposed site
2) Computation of site natural period, T_s from the borehole
3) Determine the ground type based on the ground classification scheme in accordance to site natural period, T_s
4) Select the Soil Factor, S, and corner periods T_B, T_C, T_D for the input into the response spectrum. Refer to Table 3.2 of Eurocode 8 (*BSI*, 2014).

However, in this study, no site work was done in order to obtain the borehole of the site. Hence, the site natural period, T_s was obtained based on the previous research works done by Dr Tsang (2016) to determine the suitable soil response spectrum that emphasis on the phenomenon of periodic ground shaking in Malaysia.

Analytical Procedure

In this paper, the modelling and design of an eight-storey RC building (based on Eurocode 2, Eurocode8 and Malaysian National Annex to Eurocode 8) with different peak ground acceleration seismicity in Malaysia was carried out using Robot Structural Analysis Software.

Representative Building

Figure 1 shows an eight-storey regular hotel building that was modelled to represent the typical low and medium rise structures in Malaysia. For analyses, five building models were designed according to Eurocode 2 and Eurocode 8 with various level of reference peak ground acceleration, a_{gR} to mirror the Malaysian seismic hazard for ductility class low design (DCL) and ductility class moderate design (DCM). The layout, size of the building and load applied was repeated for each model. The building was assumed to be fixed at the base. Concrete strength, beam and column size were maintained before the analysis. Modification will only be done if necessary. The detailing of steel reinforcement and concrete required was investigated and compared for the reinforced concrete (RC) design with and without seismic provision.

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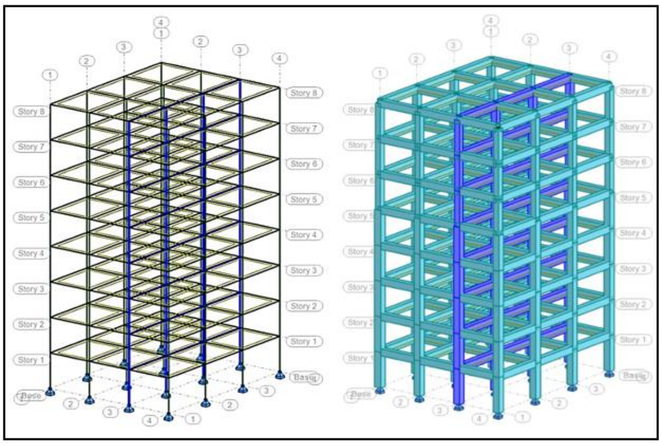

Figure 1. Model of an eight-storey regular building

Seismic Analysis of Various Case Studies

In this paper, the modal response spectrum analysis had been conducted on a typical structure frame of eight-storey RC building. For comparison, the similar building frame was used in five different case studies. In order to create case studies that reflect the seismic condition in Malaysia, several values of PGA were selected as reference peak ground acceleration, a_{gR} which is equal to 0.025g, 0.06g, 0.07g and 0.16g. All the values obtained from the Malaysia seismic hazard map. Table 1 depicts all the 5 cases in this study and their input parameters.

Table 1. Tabulation of input data for all five cases

Parameters	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Locations	Kuantan	Shah Alam	Kuala Lumpur		LahadDatu
RPGA, a_{gR}	0.03g	0.06g	0.07g		0.16g
Importance factor, γ_I	1.2 (Building importance Class III)				
PGA, a_g	0.03g	0.07g	0.08g		0.19g
Soil Factor, S	1.35 (Soil Cass D, Type 1 Response Spectrum of Eurocode)				
PSA, a_{gS}	0.04g	0.97g	0.01g		0.25g

With the parameters in Table 1, each case study was classified based on the seismicity which are "very low seismicity", "low seismicity" and "low to moderate seismicity". All frames were design according to Eurocode2 to represents current practice of RC design in Malaysia, however different seismic design approaches which is Low Ductility Class (DCL) or Moderate Ductility Class (DCM). Table 2 shows the design approaches adopted for each case.

Table 2. Design approaches for all five cases

Parameters	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Location	Kuantan	Shah Alam	Kuala Lumpur		LahadDatu
PGA, a_g	0.03g<0.04g	0.07g<0.08g	0.08g>0.08g		0.19g
PSA, a_gS	0.04g<0.05g	0.97g<0.10g	0.01g>0.10g		0.25g
Seismicity	Very low	Low	Low-moderate		Low-moderate
Design Approaches	EC2	DCL	DCL	DCM	DCM
Behaviour factor, q	-	1.5	1.5	3.9	3.9

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Modal Analysis

After computing the load cases on the model, modal analysis was performed in order to observe the vibration mode, natural period and the frequencies of building under wind load. For Case 1, since the seismic load was not applied in this case, the structural elements were assumed to be uncracked. Therefore, there was no stiffness reduction in this case. However, for other cases, the structural elements were assumed to be cracked. Therefore, the stiffness was reduced to one half. The modal responses are combined using the "Complete Quadratic Combination" (CQC) method assuming a modal damping of 5%. A total of 24 modes of vibration were considered in this analysis. After the analysis was done, the storey displacement and inter-storey drift ratio was observed for each cases and comparison was done.

Results and Discussion

Storey Displacement of Reinforced Concrete Structures

Based on Figure 2, it is observed that the maximum storey displacement of the RC structure has increased with the values of PGA. It can be said that more reinforcement is needed to maintain the stiffness of the structure when the values of PGA is high. The storey displacement of the structural system was obtained by modal response spectrum analysis based on the design response spectrum of each case. The displacement of the building depicts the deformation of the building when the earthquake happens. The structural performance of the structures was evaluated based on the interstorey drift ratio which is discussed in next subsection.

Interstorey Drift Ratio of Reinforced Concrete Structures

In this study, the interstorey drift ratio was used to estimate the structural performance of the building under seismic actions.According to EN 1998-1 (2004), limitation of interstorey drift is an additional damage limitation verification for RC design that is exposed to lateral forces in order to ensure the structure have sufficient stiffness for the functionality of the facilities. Hence, the limitation of interstorey drift controls the design approaches in most of the cases. The limitation of interstorey drift is based on the behaviour of non-structural materials that attached to the building structure(Soós, 2012). The behaviour of non-structural elements that take into account in this study is classified into brittle and ductile. Hence, by using interstorey drift limit above, the performance of the building in all cases was evaluated and compared. From figure 3, it can be concluded that the lateral drift of the structure in Case 1, Case 2, Case 3 and Case 4 is withinthe interstorey drift limit for building have brittle non-structural elements attached. This indicates that the structures have sufficient stiffness to resist the lateral force as the values of PGA in these cases are low.

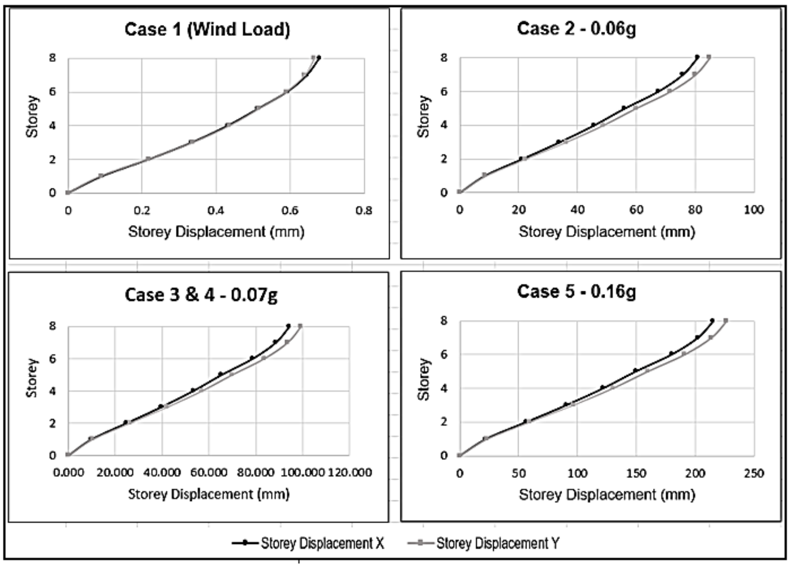

Figure 2.Storey displacements in centres of the masses in directions along X and Y

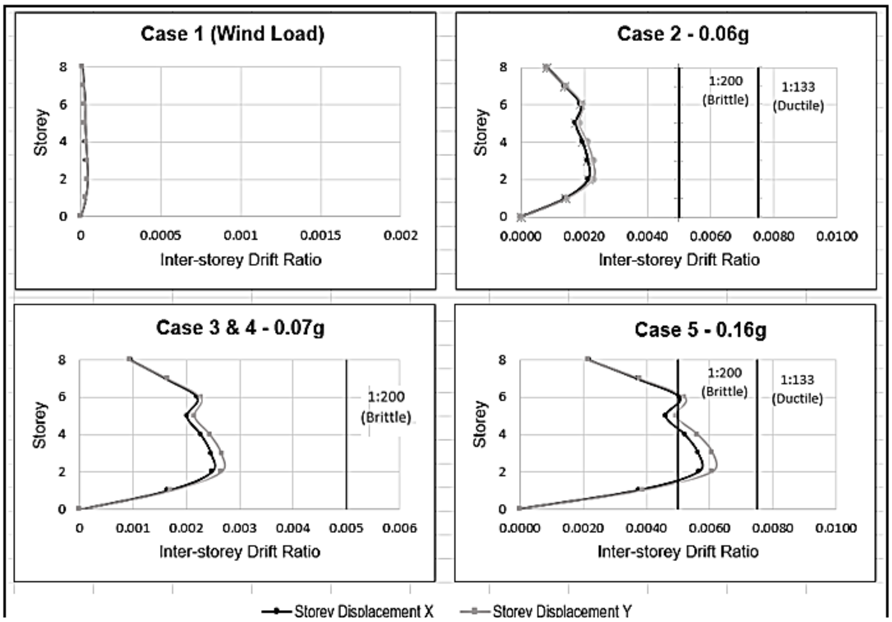

Figure 3. Interstorey drift ratio in directions along X and Y

However, for Case 5, the lateral drift of the structures has exceeded the interstorey drift limit for building have brittle non-structural elements attached. In other words, if there are brittle non-structural elements attached, it is necessary to increase the structure stiffness to reduce the interstorey drift. The high value of PGA has pushed the structures to drift over the boundary of the limit. In short, based on the performance evaluation, it clearly shows that different level of ground shaking requires different seismic design approaches to ensure the designed structures have sufficient stiffness to withstand the seismic actions. The higher the values of PGA, the design of RC structure should be more ductile.

Material Used In Comparison for Typical Beam

Since it is difficult to establish an extra cost of the seismic design, material survey was done to investigate the extra weight of extra steel reinforcement needed in beam for seismic design.Without doubt, the amount of steel reinforcement provided in RC beam design is strongly associating with the bending moment and shear force from the load imposed on the structure. Longitudinal bar is responsible to resist the bending moment, while the transversal reinforcement is responsible to resist the shear.

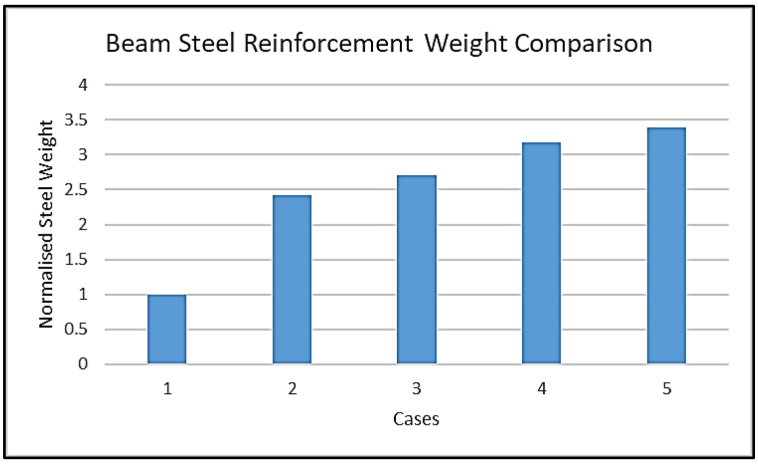

Figure 4. Normalised weight of steel reinforcement provided for a typical beam for all cases

Based on the graph, it can be observed that the total weight of steel reinforcement is increased in the range of 1 times to 2.5 times higher for frames design with seismic load. From the beam detailing in Figure 5.2, both the number of main bars and shear links increased with the values of PGA. This result can be related to the bending moment and shear force diagram of accidental limit state (ALS) shown in Chapter 4. In normal design that do not have seismic load case, for instance Case 1, ALS was not included in the design. Hence, this study has clearly shown that increment of total weight of steel reinforcement is affected by the increment of PGA values. Besides that, comparison between Case 3 and Case 4 shows that DCL is a better design approach that DCM, provided that the design acceleration ag or agS marginally exceed the threshold limit of low seismicity. Even though with a same value of PGA was applied in both case, DCL had resulted lower seismic demand and saving in the reinforcements. The main reason that contributed to this condition is due to the stringent requirement of detailing in DCM and also the minimum reinforcement requirements.

Material Used in Comparison for Typical Column

Similar to beam, normalised weight of steel reinforcement in Column 11 in all cases is shown in Figure 5. Based on the graph, it is observed that the weight of the steel reinforcement drastically increased in Case 4 and Case 5. This shows that the DCM approach requires more reinforcements compare to DCL. However, it is observed that the DCL design in both Case 2 and Case 3 requires almost same amount of reinforcement in normal RC design.

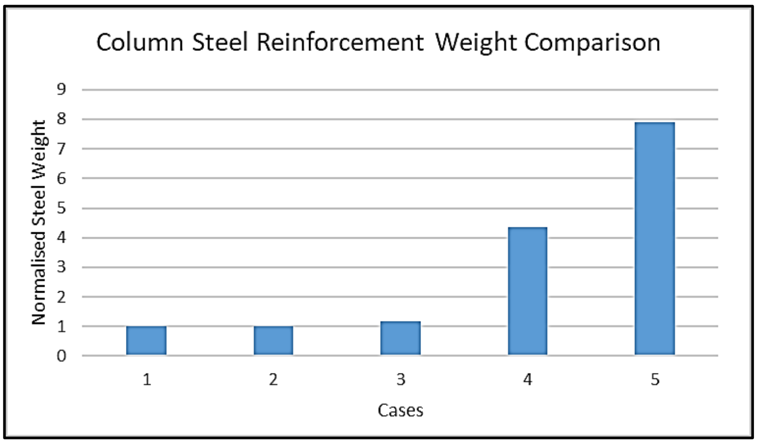

Figure 5. Normalised weight of steel provided for a typical column for all cases

As discussed in previous section, the interstorey drift ratio of the structure in Case 5 has exceed the limitation due to high value of PGA value. Thus, as a result, DCM design was adopted in this case in order to provide sufficient stiffness to the column by increasing the amount of the steel reinforcement. By this way, it can increase the ductility of the structure as steel is a very ductile material. The total weight of reinforcement for column is increased with the PGA values as higher shear force needed to be resisted.

On the other hand, the cross section of the column is also increased from 600 x 600mm^2 to 700 x 700mm^2 due to the section is overstressed if modification is not made. As a result, it shows that, the total volume of concrete is also influenced by the degree of PGA. The alternative to increase the concrete capacity is by increasing the concrete strength.

Conclusion

A total of five number of eight-storey RC building had been analysed with modal response spectrum analysis to evaluate the

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structural performance of the building. According to the classification of seismicity, the RC structures had been designed according to Eurocode 2 with and without seismic consideration to investigate the difference in material needed. Four different value of peak ground acceleration (PGA) had been considered in this research in order to cover the wide range of seismicity in Peninsular Malaysia, Sabah and Sarawak. As proposed by Eurocode 8, the value of behaviour factor, q for low class ductility (DCL) is 1.5 and 3.9 for moderate class ductility (DCM). All the frames had been evaluated with Modal Response Spectrum Analysis with software at different levels of PGA which are 0.03g, 0.06g, 0.07g and 0.16g. From the details presented in this paper, the following conclusion can be made:

1) In general, Malaysia is considered as low seismicity country. The PGA values for Peninsular Malaysia are ranged from 0.02g to 0.09g. Meanwhile, the PGA values for Sabah and Sarawak are ranged from 0.01g to 0.16g. The seismicity in Malaysia is classified into 3 zones which are very low seismicity zone, low seismicity zone and low to moderate seismicity zone. Hence, in this study, the reference peak ground acceleration, a_{gR} selected for the case studies have covered all the three seismic hazard zones for Malaysia.
2) The structural performance of the low to medium rise reinforced concrete (RC) structures was observed in terms inter-storey drift ratio. From modal response spectrum analysis, it had been proven that the inter-storey drift ratio of the structures increased with the intensity of PGA. For higher PGA, ductility design needed to be take into account in order to increase the stiffness of the structure and reduce the story drift.
3) In general, seismic zone with higher values of PGA will result in greater seismic demand which necessitate more reinforcement, higher concrete strength or greater section and longer storey drift.
4) Theoretically, using higher ductility class DCM will result lower seismic demand and saving in reinforcement. However, this study shows that, it may not apply where design PGA marginally exceeds the threshold of low seismicity definition. This is due to the stringent requirement of detailing in DCM compared to DCL and also minimum reinforcement requirements. It is suggested that DCL should be considered for the analysis and design in cases where appropriate.

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Notation

a_{gR}	Referenced peak ground acceleration, m/s^2	K	Shear stiffness
a_g	Actual peak ground acceleration, m/s^2	v	Reduction factor
g	Gravitational acceleration, m/s^2	ϕ	Diameter in mm
S	Soil factor	f_{ck}	Concrete compressive strength
q	Behaviour factor	f_{yk}	Yield strength
q_o	Basic behavior factor		
γ_I	Importance factor	DCL	Ductility class low
T_s	Site natural period	DCM	Ductility class medium
G_k	Permanent action	DCH	Ductility class high
Q_k	Variable action	PGA	Peak ground acceleration
ψ_{2i}	Quasi-permanent value of the variable action	ULS	Ultimate limit State
T	Fundamental period	ALS	Accidental limit state
M	Storey mass		