Seismic performance for vertical geometric irregularity frame structures

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Abstract. This research highlights the result of vertical geometric irregularity frame structures. The aid of finite element analysis software, LUSAS was used to analyse seismic performance by focusing particularly on type of irregular frame on the differences in height floors and continued in the middle of the building. Malaysia’s building structures were affected once the earthquake took place in the neighbouring country such as Indonesia (Sumatera Island). In Malaysia, concrete is widely used in building construction and limited tension resistance to prevent it. Analysing structural behavior with horizontal and vertical static load is commonly analyses by using the Plane Frame Analysis. The case study of this research is to determine the stress and displacement in the seismic response under this type of irregular frame structures. This study is based on seven-storey building of Clinical Training Centre located in Sungai Buloh, Selayang, Selangor. Since the largest earthquake occurs in Aceh, Indonesia on December 26, 2004, the data was recorded and used in conducting this research. The result of stress and displacement using IMPlus seismic analysis in LUSAS Modeller Software under the seismic response of a formwork frame system states that the building is safe to withstand the ground and in good condition under the variation of seismic performance.

1. Introduction

Earthquake is natural destructive phenomena of ground shaking inside earth which caused by the sudden release of energy thus caused breaking and movement of tectonic plate. The phenomenon such as tsunami, landslide, rock falls, ground settling and liquefaction happened as a result of earthquake. Furthermore, human and environment will be affected from the event that contains a very powerful energy, which leads to destruction. The sudden movement by earthquake happened when this stored energy reached a critical level, the rock fractures along a fault plane and highly violent motion at the earth’s surface [1]. When an earthquake occurs, seismic waves move out from the earthquake. Then, it is spread in all directions and breaking of rock releases energy violently moving the earth in the form of vibration. The movement of seismic waves will gradually weak because the waves travel from the focus. Generally shake will be less because the land further away from the focus [2].

Malaysia is surrounded by an active seismic bay and can be considered exceptional as it is in a non-earthquake zone as opposed to Indonesia (Sumatera Island) and the Philippines. However, if there is any big magnitude earthquake took place 350 km away from the active fault line, Malaysia will be affected as well. One of the sustainable seismic design approach is post-tensioned
seismic-resistant building system that consider damage controlled [3]. Referring to Malaysian Meteorology Department (MMD), the worst earthquake event occurred in North Sumatera, west coast of Banda Aceh at 00:58:53 UTC (08:58:53 Malaysian time) on December 26, 2004 with measured magnitudes of 9.3 on the Richter scale and the waves concerned Peninsular Malaysia. Such earthquake has caused a calamity effect to an area in Kedah (Kuala Kedah) and a few places in Penang, for instance Tanjung Bungah and Batu Feringghi. The earthquake occurred on the tectonic boundaries of the subduction zones, between the Indian plate and the Sunda plate [4].

Thus, the seismic factor is one of the important factors that can be considered during the design process of any structure. The causes of this kind of unexpected structural collapse can be from the uncertainties inherent in the ground shakings [5]. Concrete is an ‘artifial stone’ resulted from the mixture of cement, sand, course aggregates and water. The aggregates plays an important role in the overall performance of concrete because it is about 75% of concrete total volume is aggregates [6]. Any shape can be molded from fresh concrete. In 19th century, concrete became more famous after the invention of Portland cement. However, concrete is widely used in building construction and limited tension resistance to prevent it. Concrete frame is made up by mixing the fine and course of aggregate with cement and water. Frame structure consists of horizontal members (beams) and vertical members (columns) and supported by foundation at end of the ground. Shear failure and concrete crushing failur e in concrete columns can lead to the loss of gravity load-bearing capacity in the columns and potentially a total building collapse [7].

Analysing structural behaviour with horizontal and vertical static load is commonly analysed by using the Plane Frame Analysis [8]. The structural design of building typically requires performing analysis to compute action and displacement. The action is used in sizing the structure to have sufficient strength while the displacements are used to provide sufficient stiffness for the serviceability of the structure. Hence, it is widely used in plane frame analysis due to its versatility and flexibility. Most practical plane frame problems are currently solved by using Finite Element Method, which are commercially available. The intention of this study is to determine the stress and displacement of the vertical geometric irregularity frame structure due to seismic load by finite element modelling.

2. Methods of research

The important source of information in this study is architectural and structural drawing. This drawing was acquired from a civil engineer, who has built about three years ago in Sungai Buloh, Selayang, Selangor. This drawing is seven-storey of Clinical Training Centre obtained from the Development Office. Figure 1 shows the section B-B of the Clinical Training Centre. The analysis will be on structural frame, combination of beam and column. To ease the analysis process, LUSAS software was used to determine the stress and displacement seismic performance for vertical geometric irregularity reinforced concrete frame structures regarding to the topic of research.

Section B-B as the vertical geometric irregularity reinforced concrete frame structures was chosen because this section has different in floors height and continued in the middle of the building. Figure 2 shows the configuration of front elevation frame view. In addition, this study was refers to British Standard as the references. This research used BS 6399 Part 1 and BS 8110 Part 1.
The Spectral Response Analysis [9] has three distinct stages. Firstly, a natural frequency analysis, in which is to calculate the first 10 natural modes of vibration of the structures. The modes shapes such eigenvalue, frequencies and eigenvectors are stored and used in the spectral response analysis. Any information regarding the magnitudes of deformations or moment is non-quantitative from an eigenvalue analysis are obtained through the natural frequencies. Second, the spectral response calculation is performed interactively as a results processing operation using the Interactive Modal Dynamics (IMD) facility in which to performing a non-interactive spectral response analysis in LUSAS. Finite element study using LUSAS requires a description of the model configuration, the material, boundary conditions and loading. To shorten the analysis time required, the frame was modelled in 2D. The model is comprised of thick beam elements for the concrete column and beam members. The structure is fully restrained against displacement and rotation at ground level. Since the global response of the structure is required, the model of the frame is further simplified by meshing each Line with a single element. This will effectively avoid the extraction of local panel modes for individual beams and columns.

The geometry is simplified to a wire-frame on stick representation with each of the structural members being represented by Point and Line features only. The size of beam is 350 mm x 350 mm and the column size is 600 mm x 600mm. The material properties for concrete was chosen from existing material library in LUSAS where the ungraded concrete was selected. The material concrete properties of Young’s modulus, Poisson’s ratio, Density, Thermal expansion was leave to default. The support at the ground level must be fully restrained as foundation, therefore for
boundary condition a fully fixed support type is required. The self-weight of beam and column, and imposed loads that used in design buildings were considered. The peak ground acceleration (PGA) data was getting from the measuring station located at Ipoh, Perak. This data was recorded during the earthquake event happened in Acheh, Indonesia on December 26, 2004. From the data, the higher peak ground acceleration (PGA) obtained was 0.012g. This data of earthquake was used as a seismic load for vertical geometric irregularity reinforced concrete frame structures. 5% of modify damping was used in this study for seismic analysis in IMDPlus. Figure 3 shows the final irregularity frame models in LUSAS.

Figure 3. Irregularity frame models in LUSAS.

3. Results and discussion

3.1 Stress analysis
The purpose of the stress analysis is to determine this vertical geometric irregularity frame safely standing within the loading of specified forces. The stress of this type of frame shown in contours in order to visualize the distribution of the stress. The colour of contours show the level stresses on the frame structures. Figure 4 shows the stress contour for mode shape 1, the maximum stress is 40.5756 kN/m² at line of column (A-B/12) and the minimum stress is -40.56kN/m² at line of column (A-B/2). The line of column coordinate can referred Figure 2: Configuration of front elevation frame view.

Figure 4. Stress contour for mode shape 1.
Figure 5 shows the stress for mode shape 3, the maximum is 347.58 kN/m² at line of beam (G/5-6) and the minimum is -198.541 kN/m².

Figure 5. Stress contour for mode shape 3.

Figure 6 shows the stress for the mode shape 5, the maximum stress is 3.67601E3 kN/m² at line of beam (E/9-10) and the minimum stress is -1000.467 kN/m² at line each column.

Figure 6. Stress contour for mode shape 5.

From the result of stress analysis, the maximum value for stress is 3.67601E3 kN/m² at line of beam (E/9-10) under mode shape 5. Besides, the maximum value for displacement is 0.255182E-3 m at joint (G-6) of beam and column under mode shape 3. The mode shape depends on eigenvalue. The eigenvalue is a condition where to set for an initial of structure imperfection. In the real condition, the eigenvalue defects due to temperature, weather, transportation, installations etc [10]. By the seismic load setup on the frame structures, the determination of natural frequencies under mode shapes is important part to show the effects of the frame under the stress analysis. Overall, stress is proportional to eigenvalue in stress analysis. The stress would be increase as the natural frequency increase too due to mode shapes. The increasing of stress value from the seismic loading on the frame structures can cause fatigue and
perhaps the ultimate limit state is reached when the applied stresses actually exceed the strength of the structure elements. This can cause the structures of beam and column failed and collapse when the strength of seismic load exceeds the strength of the structures.

3.2 Displacement analysis

The purpose of this displacement analysis is to determine this frame safe due to seismic performance. The displacement of the vertical geometric irregularity frame structures shown in values and modes shape in order to visualize the distribution of the displacement. Besides, this research also to compare with previous research to see the result of differences displacement by using Finite Element Analysis and other software. The maximum displacement for mode shape 1 is 15.3085E-6 m at point G-12 and the minimum displacement is -13.059E-6 m at point D-12 as shown in Figure 7. The mode shape of displacement is sway to the left hand side inclined to the support of frame because the loading of the building added with seismic load can give impressed to the frame of the building. The maximum displacement for the mode shape 3 is 62.3836E-6 m at point H-6 and the minimum displacement is -60.0923E-6 m at point H-8 as shown in Figure 8. The mode shape of this displacement is sway to the right hand side movement such as S-shape mode.

![Figure 7. The displacement of mode shape 1.](image1)

![Figure 8. The displacement of mode shape 3.](image2)

The various effect of displacement is based on the sway shape under seismic load. From the result of displacement, the maximum displacement is on the top of mode shape 3 because this displacement was sway such S-shape movement, it is faster absorbed the seismic load and largely movement of sway movement. Hence, it is also slowly for stop to become actual shape of
This research used Finite Element Analysis (LUSAS) meanwhile there was previous research used Model Pushover Analysis (MPA) for studies of vertical geometric irregularity frame structures. Figure 9 and Figure 10 show the displacement of mode 1, 2, 3 and Nonlinear Time History Analysis (NLTHA) for VGI-I, and VGI-II respectively [11]. This study is to compare in order to determine displacement value of vertical geometric irregularity frame by using LUSAS and MPA as shown in Table 1.

![Figure 9](image1.png)  
*Figure 9. Displacement of mode 1, 2, 3 and NLTHA for VGI-I [11].*

![Figure 10](image2.png)  
*Figure 10. Displacement of mode 1, 2, 3 and NLTHA for VGI-II [11].*

| Mode | LUSAS | MPA |
|------|-------|-----|
| VGI-I | 0.0015 | 19.5 | 17.0 |
| VGI-II | 0.0031 | 19.8 | 17.3 |
| 3 | 0.0062 | 20.0 | 17.5 |

By using the result in Table 1 for seven-storey of building, the results show the comparison displacement value between LUSAS and MPA. The largest magnitude of 6.9 on the Richter scale and the seismic waves spread around 77 km to the VGI of building [11]. The distance of
earthquake centre and the building was very nearest. For this research by Finite Element Analysis (LUSAS), the distance from earthquake centre (Aceh, Indonesia) to Malaysia was approximately 500 km. This study obviously shown the displacement value different was too high following the mode. The displacement of this research was smaller than previous research because of the difference distance very large. In fact, the seismic wave move very faster according to magnitude of Richter scale, the displacement was reduced in order when the distance was far away from the earthquake occurs.

3.3 Modal analysis
The modal analysis represents the information of mode shape, eigenvalue and natural frequency for vertical geometric irregularity frame structures due to seismic performance. The natural frequency is depends on the value of the eigenvalue. Frequency is understood as the number of repeating events in a given unit of time. For every frequency, there is a period which is the duration of time between one event of the same type and the next. The results of mode shape, eigenvalue and natural frequency as shown in Table 2.

| Mode shape | Eigenvalue | Natural frequency (Hz) |
|------------|------------|------------------------|
| 1          | 123.085    | 1.76572                |
| 2          | 1006.49E3  | 5.04922                |
| 3          | 3482.11E3  | 9.39164                |
| 4          | 7143.53E3  | 13.4517                |
| 5          | 9761.11E3  | 15.7242                |

4. Conclusions
The variation of stress under seismic performance loading on the vertical geometric irregularity frame structure is normally stress in the frame due to loading of building and seismic wave. Mode shape of eigenvalue is represents the certain place of critical stress where the maximum stress occurs due to seismic performance. From the overall results of stress, the vertical geometric irregularity frame can safely withstand by the variation of loading and force against to this frame structures.

Furthermore, this studies also to determine the displacement of the vertical geometric irregularity due to seismic performance. From the overall results of mode shape, the frame structure was sway in the balance condition movement where the displacement is not very large movement. Hence, the vertical geometric irregularity is in good condition and safely withstand under the variation of loading and force.
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