PAPER • OPEN ACCESS

Structural retrofitting proposal for representative school facility

To cite this article: M N A Mansor and Lee Choon Siang 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **244** 012045

View the article online for updates and enhancements.

Structural retrofitting proposal for representative school facility

M N A Mansor[1] and Lee Choon Siang[2]

[1]Pengarah Kejuruteraan Pakar (Struktur) Cawangan Kejuruteraan Awam dan Struktur, Ibu Pejabat JKR Malaysia
[2]Bahagian Rehabilitasi, Cawangan Kejuruteraan Awam dan Struktur, Ibu Pejabat JKR Malaysia.

Abstract. The recent JKR study for "Vulnerability Studies to Existing Building due to Seismic Activities in Sabah" had discovered considerable number of existing buildings suffer different levels of risk under seismic actions. Recognizing these existing building does inherit some design deficiencies in their earlier design stage, these deficiencies can be overcome either by enhancing the performance existing members or adding new structural elements to achieve the desired earthquake resistance level in terms of section capacity and interstorey drift. Few approaches outlined within the FEMA 547/2006 "Techniques for the Seismic Rehabilitation of Existing Buildings' had been used with this study in seek for most suitable retrofitting method in terms of performance, constructability and cost effectiveness. Three types of feasible retrofitting methods were covered within this paper, the performance comparison among retrofitting each method would be discussed as well. The evaluation criteria and upgrade schemes have been derived from analysis and assessment for this school facility building. The comparison for all the proposed methods of retrofitting an existing building can be measured in the terms of cost over average performance ratio. It can be concluded that each method is having specific advantages in the aspect of structural performance and cost-effective measures subjected to the characteristic of each studied approach.

1.0   Introduction

In most seismic retrofitting scheme, vertical oriented components such as columns and walls are always the main targeted element for strengthening due to the significance in providing either lateral stability or gravity load resistance [1]. In order to design an efficient retrofit scheme, it is imperative to have a thorough understanding of the expected seismic response of the existing building and all of its deficiencies. In this study, three (3) approaches which are much traditional way have been adopted. These methods are namely (a) enhanced concrete moment frame, (b) additional independent shear wall and (c) wing wall method [2]. For most government structures which suffered damages during most earthquake event in the past, the common approach was to repair and restoring those structure back to earlier intended design criteria, without consideration of seismic requirement. As such it is believed that there is a need to initiate with some seismic retrofitting scheme government structures which may start with the school facilities [3]. As strategy to apply a single workable retrofitting scheme to maximum numbers of existing building, a representative model was selected within total fifty-six (56) building within the vulnerability study database [4]. A group of six (6) numbers of school facility

structure were found with identical geometrical and design. This school facility structure was selected as representative model for this retrofitting study. The representative model is a five (5) storey building which is symmetrical in plan and regular in vertical arrangement [5]. The typical plan and front view of the structure is shown in Figure 1 and Figure 2. The empty space with parking facilities at the ground floor level as indicated Figure 2 may result in the "Soft Story" effect [6,7].
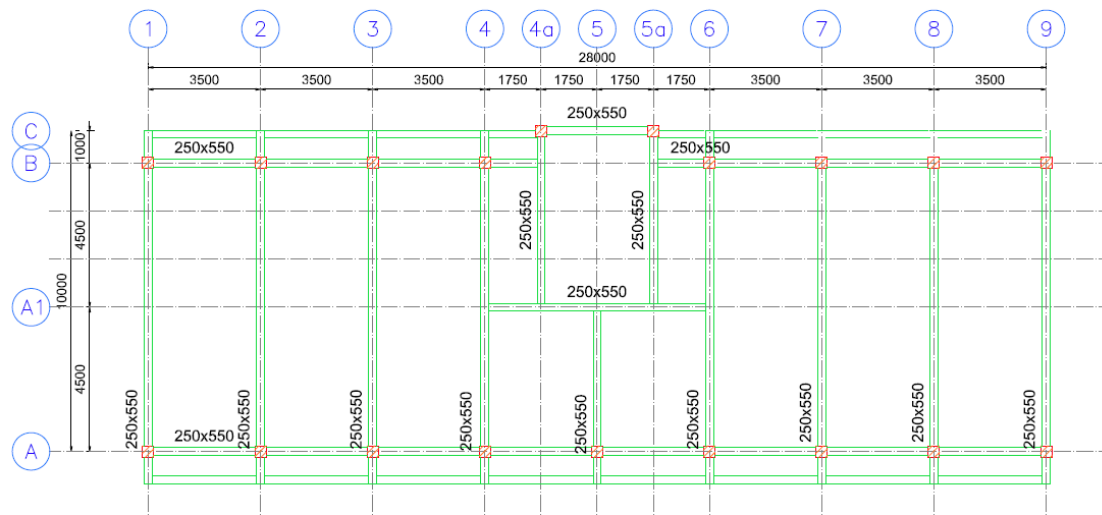

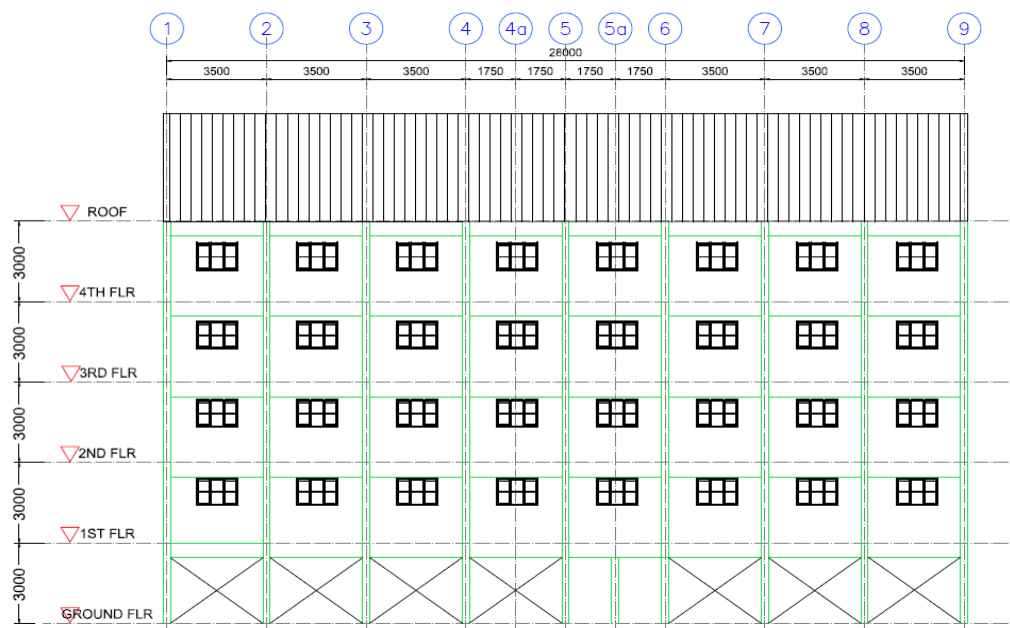
Figure 1. Plan View

Figure 2. Front view

2.0   Analysis and Assessment

Three-dimensional Response Spectrum Analysis (RSA) has been carried out to identify deficiency on this building. The building was analysed by using Staad-Pro dynamic analysis with rigid diaphragm added at each floor level. The 3D frame modelling is shown in Figure 3.
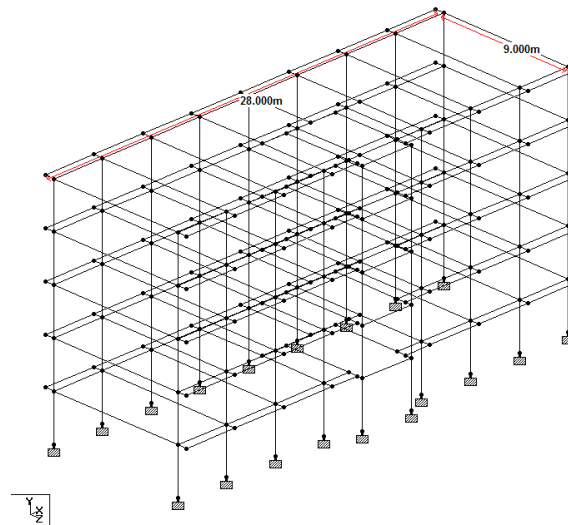
Figure 3. Staad Pro Three-dimensional Model

The dimension and properties selected building had also been verified at site in order to obtain that uncertain information made available in drawing database. One of the inspected representative buildings is shown in Figure 4.
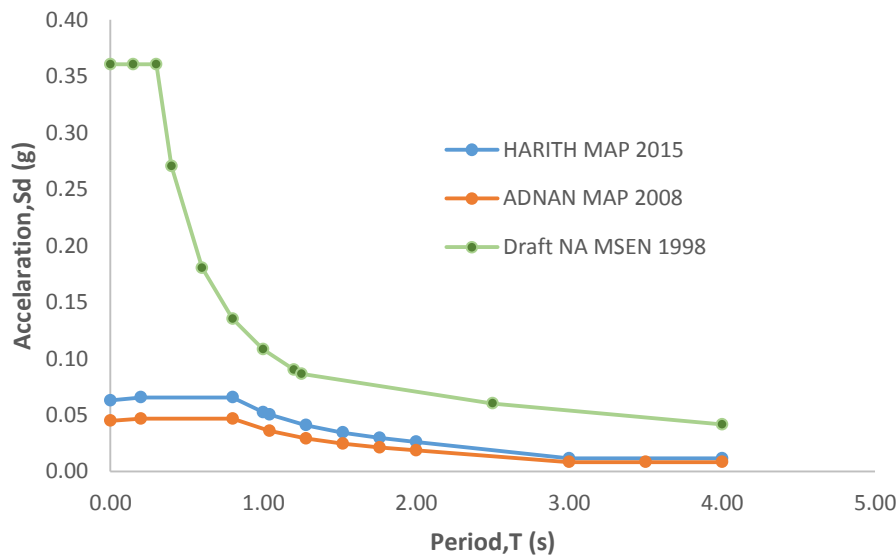

Figure 4. Photo of Representative Building

2.1   Parameters Adopted

The analytical assessment of the building capacity was conducted based on several references as tabulated in Table 1. The building is classified with importance class type III in the assessment with the importance factor, γ_I value of 1.2 was considered. Response Spectrum Modal analysis were carried out in both X and Z direction by taking into account of seismic acceleration response spectrums which are plotted in Figure 5.

Table 1 Seismic Design Parameter

Parameters	Map/approach	Value
Design PGA $a_g = \gamma_I \cdot a_{GR}$	Adnan A et. al	0.08 g
	Harith N.S.H	0.06g
	Draft NA MSEN 1998-1	0.14g
Ground Type	Adnan A et. al	D
	Harith N.S.H	D
	Draft NA MS EN 1998-1	R
Behavior Factor, q	Adnan A et. al	3.6
	Harith N.S.H	3.6
	Draft NA MS EN 1998-1	N.A.

Figure 5. Acceleration Response Spectrums

3.0   Deficiencies Observed

RSA results indicate that all beam elements are having sufficient structural capacity to resist seismic actions under the considerations. However, some columns were found having inadequate resistance against seismic actions with the considered load combinations. The column combined axial and moment interaction curve shows the column capacity for 350mm x350mm reinforced concrete against the both seismic actions according to Adnan et al. [3], Harith et al. [4] and draft version of National Annex. The seismic responses in column axial force vs moment were represented by points within the chart. Four (4) elements on columns are found lying beyond the capacity curve. The columns with deficiency of inadequate capacity are member number 3104, 3304, 3309 and 3313 as shows in Figure 6 and Figure 7. All these four members on left wing are found subjected to lower axial force due to the overturning effect of the applied seismic in the forward direction of z-axis. The lower axial force with the corresponding high bending moment resulted the section under the design capacity as indicated in Figure 7. It is expected the similar effect would occur on the opposite right wing columns if the seismic action was the reverse direction. Therefore, it can be concluded that both wings of columns

require certain strengthening procedure to enhance the existing column capacity in order to achieved targeted the seismic performance.
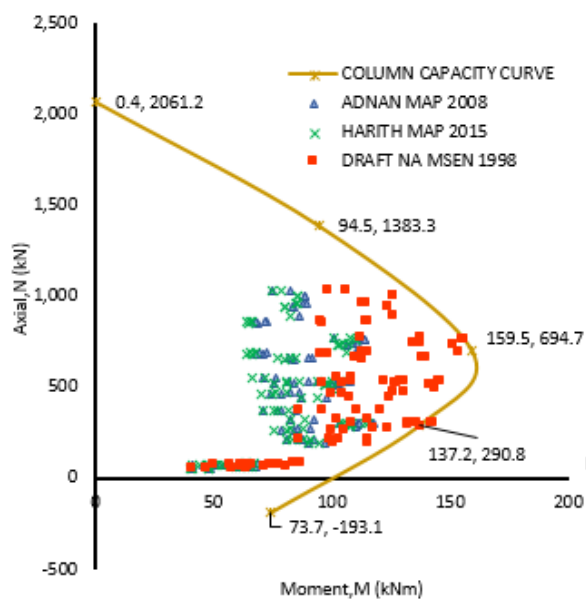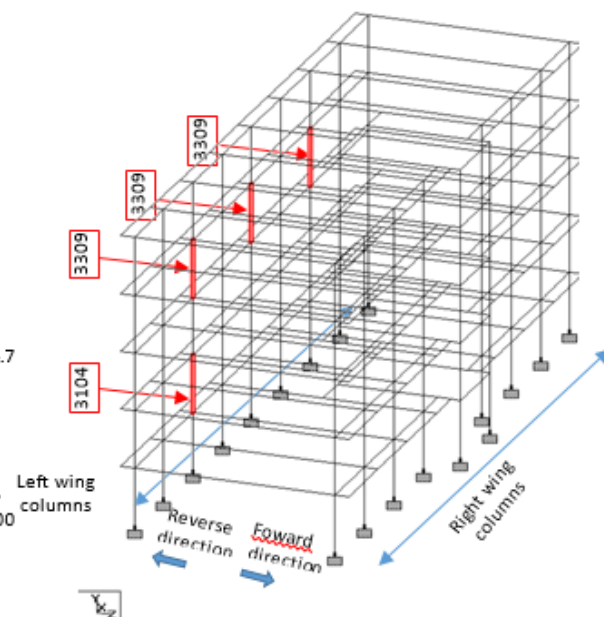

Figure 6. Column Interaction Curve   **Figure 7**. Columns with Inadequate Capacity

4.0   Proposed Retrofitting Method

Three (3) typed of feasible retrofitting methods was introduced in this study. Each method varies in the constructability and structural performance. The detail the retrofitting methods are presented below.

4.1   Retrofitting Method 1 – Enhance Concrete Moment Frame

This is of the most conventional method for enhancement of section capacity by enlargement of the existing member size. It is proposed to increase the section depth in the major in plane direction from existing 350mm to 500mm. the proposed section enlargement is illustrated in Figure 8. The dotted line shows the capacity of enlarged section which offset further beyond existing column capacity path. It can be noticed that the plot of moment-axial results from draft NA MS EN 1998 all fall within the new enlarged section 500mmx450mm curve.
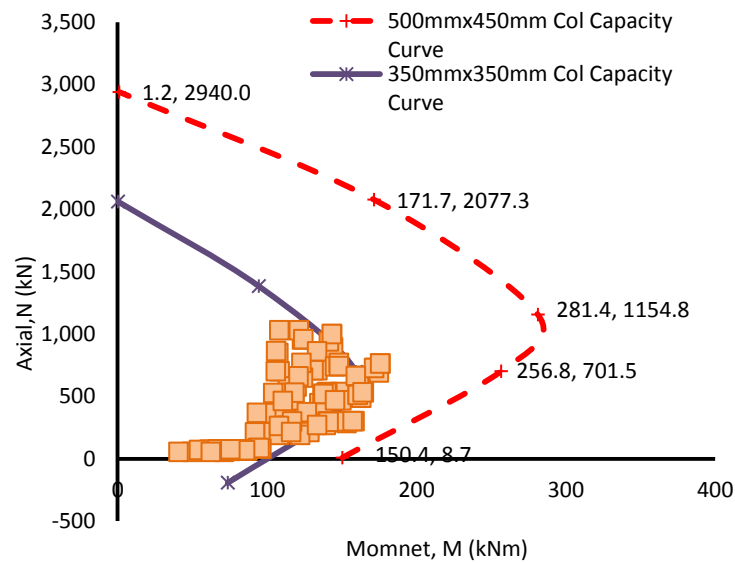
Figure 8. Enlarged Column Capacity

All columns within this structure are required be retrofitted using the proposed column enlargement method in order to achieve the desired seismic resistance. With the increase of section size and capacity, the whole moment frame would be enhanced to be stiffer and having better performance. The proposed sketches of the column enlargement are shown in Figure 9.
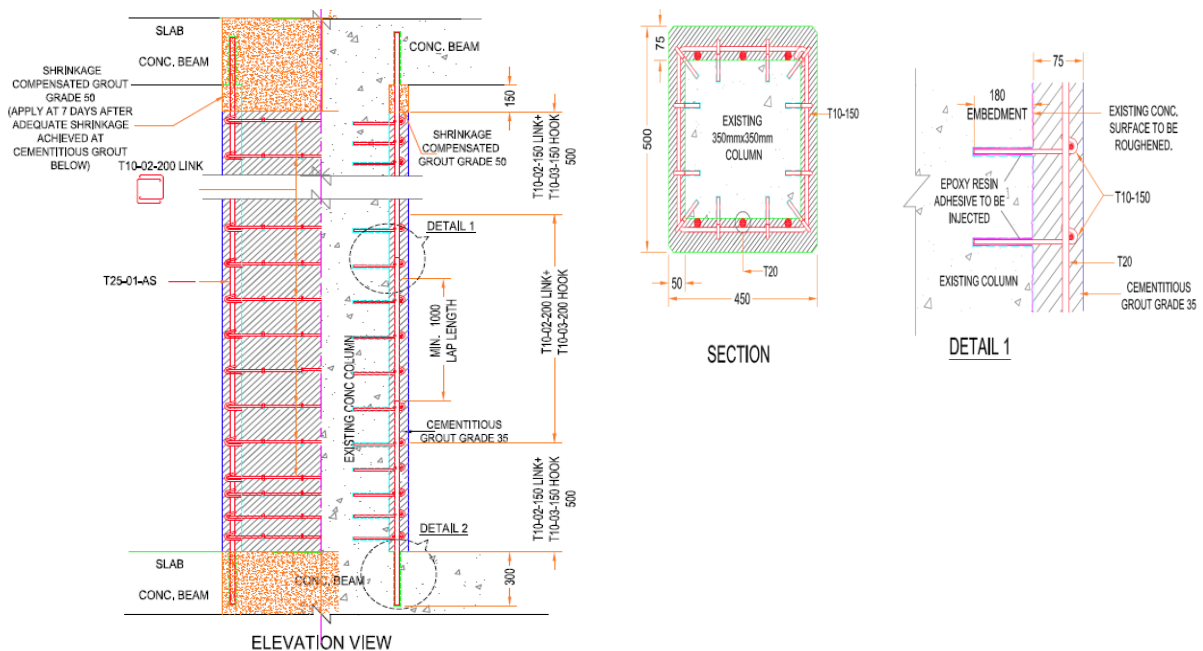

Figure 9. Proposal for Column Enlargement

4.2   Retrofitting Method 2 – Independent Shear Wall with Foundation

The second method proposed to install additional 250mm thick reinforced concrete shear wall at the external faces and middle staircase location. These shear wall shall be supported on independent foundations which were intended for resisting the lateral component and overturning moment induced by the mass subject to seismic response. Micropile system was proposed here to minimise the vibration caused during the period of foundation works in progress. The arrangement of the independent wall system is shown in Figure 10. Construction detailing of the independent shear wall is presented in Figure 11.
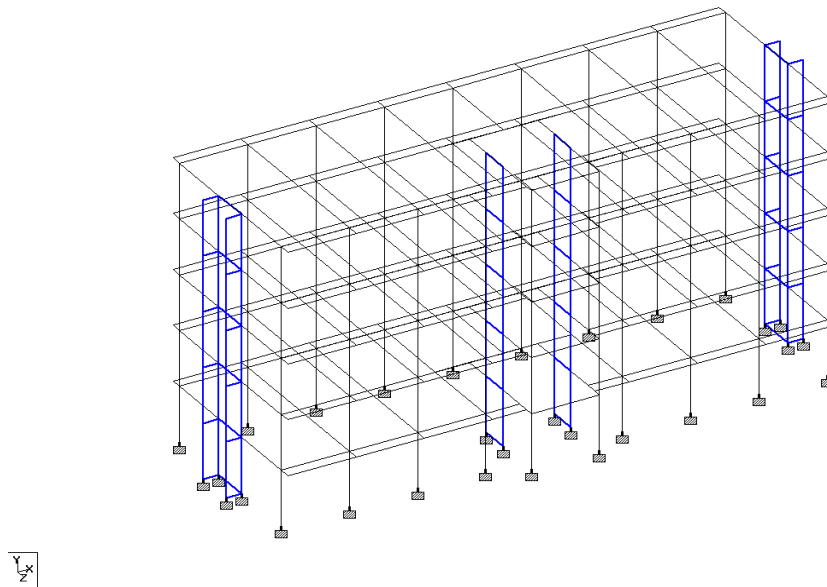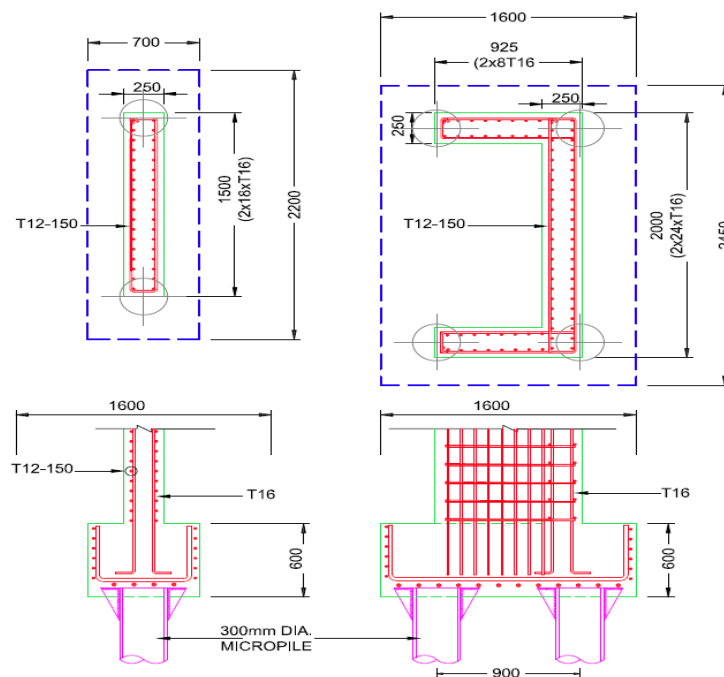
Figure 10. Independent Shear Wall Modelling in Staad Pro

Figure 11. Proposed Shear Wall Detailing

4.3 Rehabilitation Method 3 – Wing Wall Method

The independent shear wall method may strengthen the structure against lateral seismic action in both directions effectively, but the additional foundation will also introduce significant cost increment especially for site location with weak soil profile. Therefore, a third method has been studied here by adding the additional wing walls without modification to existing foundations. The general layout of the wingwall system is shown in Figure 12 and the proposed construction detail is shown in Figure 13.
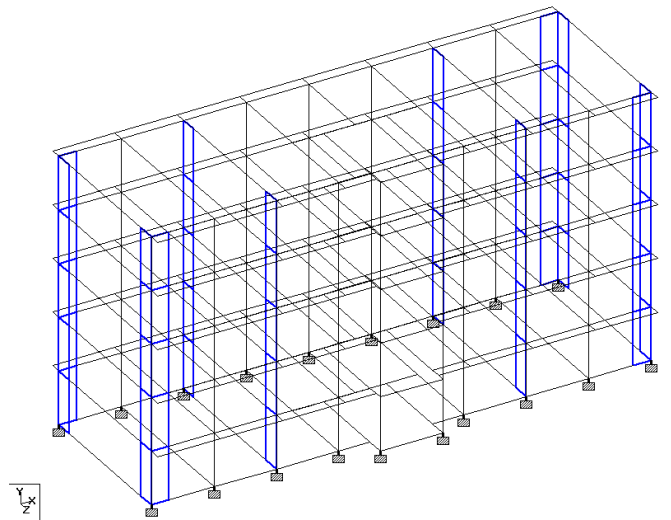

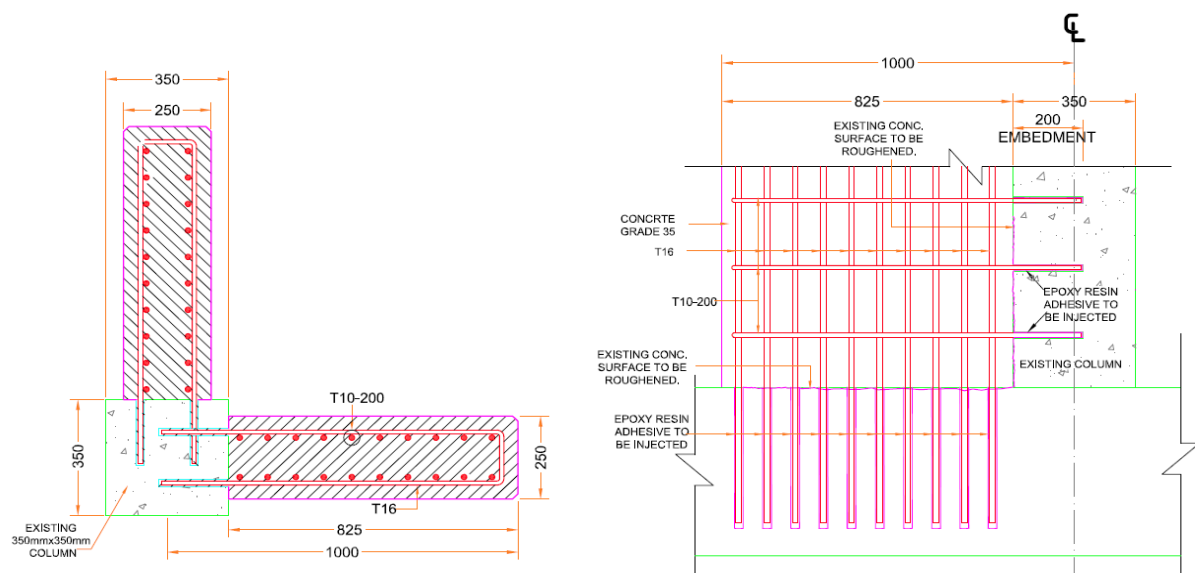**Figure 12.** Wing Wall Method Modelling in Staad Pro

Figure 13. Proposed Wing Wall Detailing

4.4 Comparison among Retrofitting Methods

For performance comparison, the interstorey drift and total drift improvement for both X-direction and Z-direction are represented in Figure 14 and Figure 15. As overall all three (3) methods mentioned above could effectively reducing the total drift of the structure. The independent shear wall system shows the highest total improvement in the Z-direction at 51% improvement. However, the total drift in the X- direction was minimal at merely 3% of improvement. The interstorey performance varies from each method. On the other hand the enlarged column and wing wall method shows more consistency in the drift performance. In general, it can be observed that the interstorey drifts increase at 3 meter to 6 meter height and the drift reduce at all levels above 6 meter height. This reversing of interstorey drift may due to the reduction of loading at the roof.
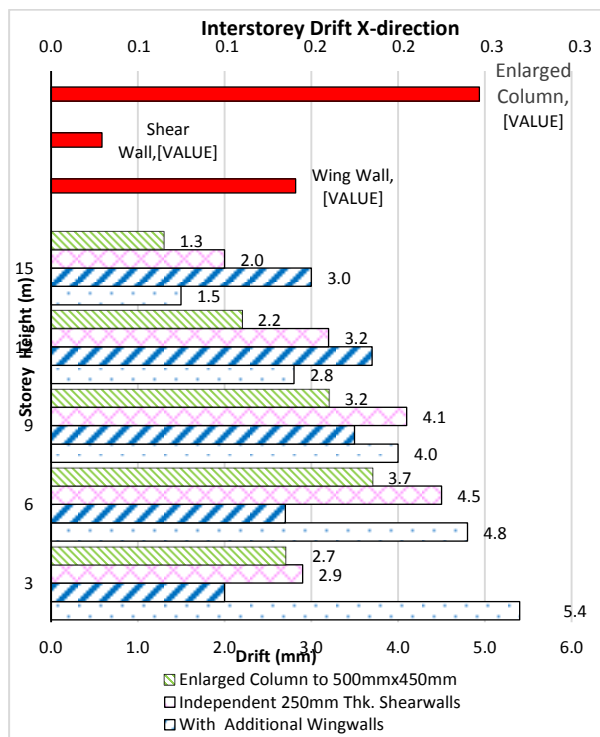

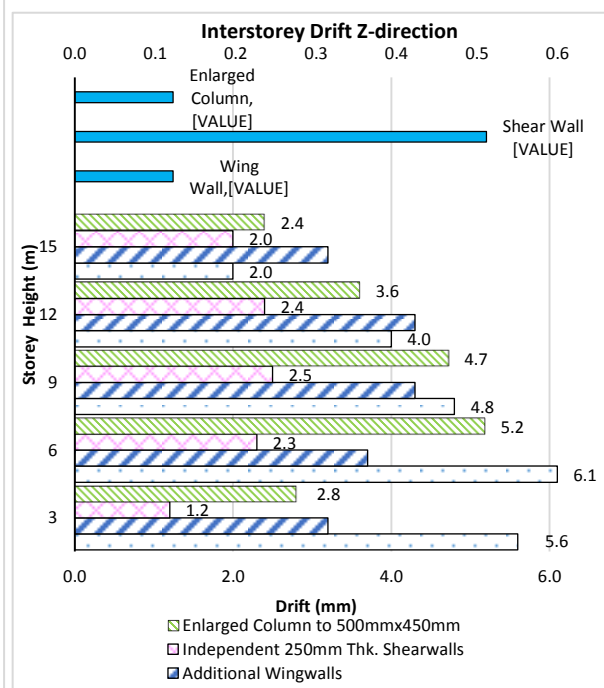**Figure 14.** Interstorey Drift in X Direction   **Figure 15**. Interstorey Drift in Z Direction

5.0 Discussion

The cost effectiveness of the retrofitting methods can be measured by Cost over Average Performance (CAP) ratio in Table 2 Cost/Average Performance Ratio. The lower value indicates the better cost effectiveness of the proposed system. Obviously, the Enhanced Concrete Moment Frame method shows the most cost effective ratio at 1,656. Nevertheless, this method may involve more massive scale of architectural and demolition works as all columns needs to be enlarged to required sizes. Furthermore, the cost do not include costs for the replacement of window and door frames, which will increase the CAP ratio. The other two methods do not involve replacement of windows/doors frames and may end up to be the cheaper option. Independent Shear Wall with independent foundation will be the most expensive option but this method gives the best seismic resisting performance. But, the disadvantage will be that it involves a lot of underpinning works and may slow the rehabilitation process.Wing wall option gives the best option to the building owner for in providing sufficient seismic resistance without much disturbance to the current building with reasonable upgrading cost.

Table 2 Cost/Average Performance Ratio

Retrofitting Methods	Avg. Performance (A)	Est. Cost RM (B)	Ratio B/A
1 Enhance Concrete Moment Frame	18%	29,811	1,656
2 Independent Shear Wall with Foundation	27%	103,316	3,827
3 Wing Wall Method	15.5%	44,100	2,845

6.0   Conclusion

It can be concluded that Enhanced Concrete Moment Frame was found to be the most cost-effective method among the three options. However, the cost estimation made within this report was merely based on the structure cost only and do not include other incidental costs associated to the works. Therefore, this method may cost more as it will involve massive architectural works such as doorways and windows reconstruction with all the columns needed to be enlarged. It should be highlighted that the wingwall method may be worth for consideration here. This method provided much consistence drift improvement in both X and Y direction and could cost equally to Enhanced Concrete Moment Frame if the total reconstruction cost of architectural components were taken into consideration.

References
[1]   M N A Mansor, L C Siang, A Ahwang, M A Saadun and J Dumatin (2017) *Vulnerability study of existing buildings due to seismic activities in Sabah,* 1st National Colloquium on Wind and Earthquake Engineering 2017
[2]   FEMA NEHRP (2006) *Techniques for the seismic rehabilitation of existing buildings, FEMA 547.* Building Seismic Safety Council for the Federal Emergency Management Agency.
[3]   Azlan Adnan, Hendriyawan, Aminaton Marto & B. Selvanayagam, P.N (2008). *Development of Seismic Hazard Maps of East Malaysia* Advance in Earthquake Engineering Applications. Book Chapter, Penerbit UTM
[4]   N.S.H. Harith, A. Adnan & A.V. Shoushtari (2015), *Seismic Hazard Assessment of East Malaysia Region*, International Conference on Earthquake Engineering and Seismology (IZIIS-50), 12-16 Mei 2015, Floating MSC ORCHESTRA cruiser
[5]   MS EN 1998-1 Eurocode 8. (2015). *Design of structures for earthquake resistance. General rules, seismic actions and rules for buildings technology.*
[6]   Draft Annex for MS EN 1998-1 Eurocode 8. (2015). *Malaysia national annex to Eurocode 8*
[7]   ASCE standard ASCE/SEI 41-13: American Society of Civil Engineers (2014), *Seismic evaluation and retrofit of existing buildings.*