PERFORMANCE BASED EARTHQUAKE EVALUATION OF SCHOOL BUILDING IN SRILANKA

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ABSTRACT

This study quantifies the seismic vulnerability of typical three storied class room building located in SriLanka. A significant feature of this reinforced concrete frame building is that this was not designed for seismic effects. Besides, there are some infill brick walls also.
A methodology given in “Guidelines for Seismic Performance Assessment of Buildings”(ATC-58) was followed as it was expected to study consequences of earthquake. As per ATC-58, intensity based assessment was considered for Hazard Analysis while the Structural Analysis was carried out to obtain engineering demand parameters (EDP) such as story drift and story acceleration. Besides, a Damage Analysis was carried out not only for structural members but also for non-structural members. Pushover analysis was done in order to define damage states of the structural while Loss Analysis was carried out to quantify the direct economic loss.

1.INTRODUCTION

School buildings have been considered as post-disaster buildings or special buildings in many countries considering its’ role after an earthquake. As per HAZUS-MH MR3 Technical Manual also, school buildings are considered as essential facilities. Therefore, it is it is very important to design school buildings to withstand seismic effects.

However it has been realized that yet non of the school buildings in SriLanka have been designed to mitigate seismic effects. Therefore, it is important to investigate the seismic vulnerability of at least a single school building in SriLanka. A three storied building was selected for investigations because this is the most typical building all over the country. In order to achieve above objectives, a methodology given in “Guidelines for Seismic Performance Assessment of Buildings” (ATC-58) developed by Advanced Technology Council was used. Accordingly, an assessment of performance capability was carried out for this building.

The software STERA 3D (Dr.T.Saito,2005) was used to perform pushover analysis and nonlinear response-history analysis. Pushover analyses were used to define the story capacity limit states of the modeled structure. Pushover analyses were run several times to determine quantitative limit states of inter-story drift. Nonlinear response-history analysis was used to determine the engineering demand parameters. A simple calculation method was used for loss calculations. The repair method was proposed as per in the context of SriLanka and the prevailing rates were used for cost calculation.

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2.BUILDING OVERVIEW

Even though this building has been designed for wind loads, it can be proved that the wind load is very small compared to the seismic load. The designed strength of concrete has been considered as 20MPa. Since this is cube strength of concrete, it was converted into cylindrical strength as 16Mpa. The strength of all the main reinforcement steel is 460Mpa while the strength of shear reinforcement is 250Mpa. Besides, the compressive strength of bricks has been estimated as 3Mpa as quality of the bricks are poor. The compressive strength of mortar has been considered as 4Mpa. The detail of this building is shown in Figure 1. A size of 300mmX375mm columns are located from first floor to third floor level and corner columns from third floor to roof level. Size of the other columns from third floor to roof level are 225mmX375mm. Size of all the beams spanning in longer direction of the building is 225mmX22mm. However, the size of beams spanning shorter direction is 300mmX650mm except roof level. The size of beams spanning in shorter direction at roof level is 225mmX450mm. Besides, there are some masonry infill walls spanning in the shorter direction. Here after, the longer direction of this building was considered as X-X direction while the other direction was considered as Y-Y direction.

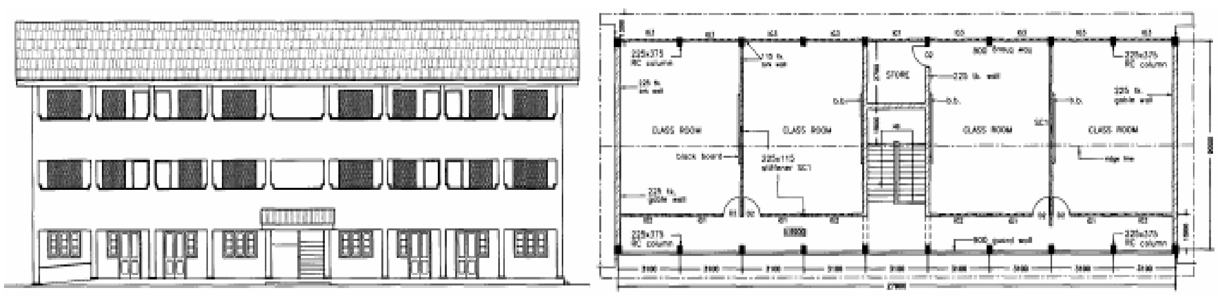

Figure1. Detail of the building

3.HAZARD ANALYSIS

As we are aware, earthquakes can also occur within the single tectonic plate and are referred to as intraplate earthquakes. SriLanka is also located within one of such area know as Indo-Australia plate. Intraplate regions have been historically described as areas of low to moderate seismic hazard. The effects and risks involved with intraplate earthquakes have been studied, but not yet fully understood. Especially in SriLanka, lack of reliable data on past earthquakes hinders the study on seismicity around SriLanka. However, as per available records, it is evident that SriLanka is not a seismically inactive country but the earthquake could occur at long recurrence period

According to the available data, it was suggested for Colombo an earthquake of magnitude close to M_L=6 on Richter scale with a return period of 200-400 years; a design acceleration of 0.2g(196cm/s^2) is considered as the horizontal component of the earthquake while the vertical component is neglected at this stage. Besides, the attenuation relation developed by Fukushima and Tanaka was applied for earthquake of M_L=6 on Richter scale and a site of 5km away from the epicenter. It was found that the Peak Ground Acceleration as 186.4 cm/s^2 which is quite similar to suggested acceleration 0f 0.2g. Therefore, it was decided to follow intensity based assessment with a acceleration of 0.2g (196cm/s^2).

4.STRUCTURAL ANALYSIS

Since this is an existing structure, structural designs were not carried out. However, the failure modes of the building were investigated and it was revealed that all the beams and columns failed because of flexure. Besides, it was revealed that the failure modes of the columns and beams are columns governed by the flexural beam and flexural column in X-X and Y-Y directions respectively.

Displacement control pushover analysis was used for this study. First of all, a target displacement for the structure was established as 1/50. The contribution of the infill walls to seismic resistance was also considered in this study. The effect of P-Delta was not considered for the analysis because of the low rise building.

According to pushover analysis, it was revealed that the soft-first story mechanism would be formed in Y-Y direction and more interestingly it was observed that the obtained failure modes were agreed with that obtained from manual calculations

Since it was observed several infill masonry walls, an attempt was made to develop an analytical model. The shear resistance at cracking, maximum and ultimate was calculated as per Kabeysawa, T., Mostafei, H. It was noticed that the respective displacements are almost similar in analytical model and results of pushover analyses.

Nonlinear Response-History Analysis was used to determine the engineering demand parameters(EDP) of the structure with 5% damping under suite of 11earthquake ground motions. The suite of earthquakes was scaled to spectral acceleration of 196gal at the period of 0.903sec and 0.522sec because it was expected to analyze the structure for both directions.

5.DAMAGE ANALYSIS

According to ATC-58, it is necessary to assess the possible distribution of damage to structural and nonstructural components using the response data from the structural analysis together with data on the building configuration. However, the damage analysis of this study was concentrated mainly on structural components and masonry infill walls.

Accordingly the structural damage states such as slight, extensive and complete of structural members and masonry walls were classified based on the pushover analysis results. The damage states are shown in Figure.2. Besides, the repair methods for each damage state were studied.

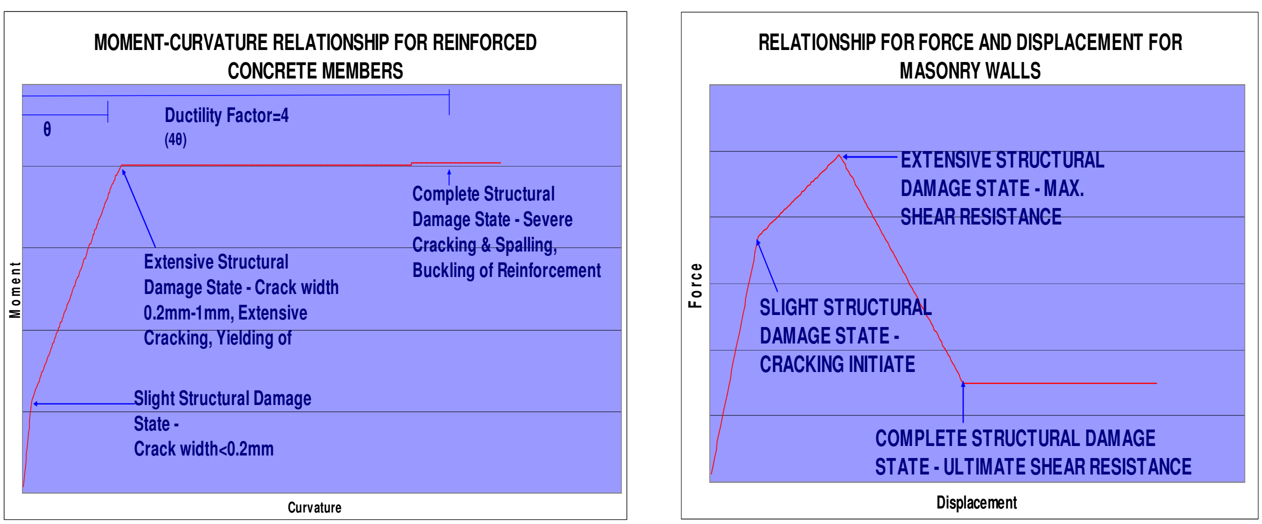

Figure 2. Damage states of structural members and infill masonry wall

It was observed that all most all of the beams spanning in X-X direction reached the complete damage state in case of pushover analysis was performed in X-X direction. Thus, it was determined that the base shear coefficient of this structure at X-X direction is 0.08 and this is not sufficient even for regions where seismicity is very low. Besides, story drift at respective damage state was almost same for second and third story. However, it was somewhat different in roof level and out of thirty six(36) beams spanning X-X direction, only twenty beams reached complete damage state.

Similarly, pushover analysis results on Y-Y direction were also studied. It was found that only some of the columns reached these damage states. The beams spanning Y-Y directions did not reach even the slight structural damage state. Even at second story only sixteen columns had reached the complete structural damage stage. However, it was found that the base shear coefficient of Y-Y direction is 0.245, as such that is sufficient enough for low seismicity countries like SriLanka.

In addition, it was decided to define structural performance level of this building based on Prestandard and Commentary for the Seismic Rehabilitation of Building published by FEMA(FEMA 356). Therefore, an attempt was made to represent the probable Structural Performance Levels of this building in terms of top drift. According to the results of pushover analysis, the relationship of top drift versus base shear coefficient for both directions were drawn and shown in Figure 3.

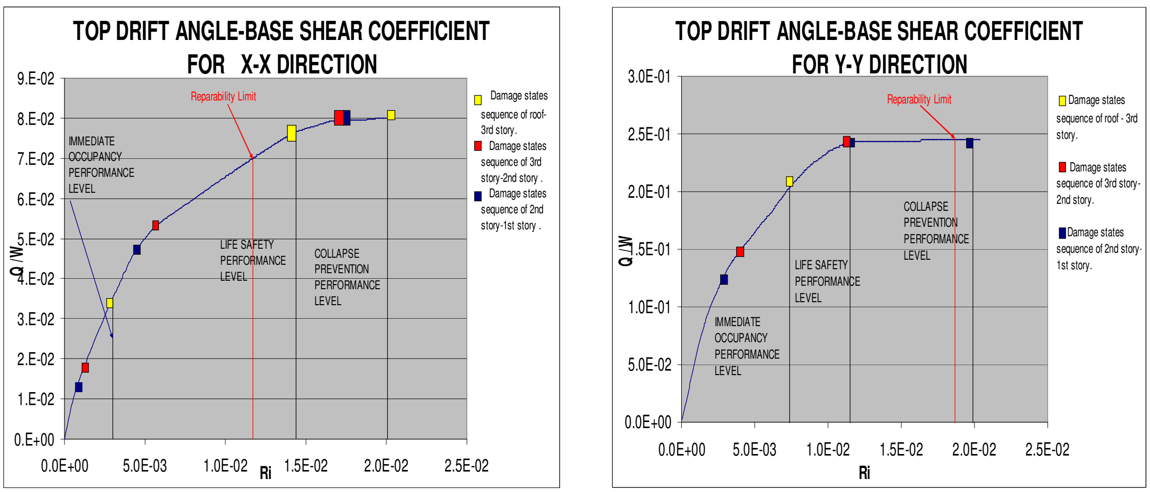

Figure 3. Damage sequence of members X-X and Y-Y direction

In addition to concrete frame structure, behavior of the masonry infill walls were studied according to the above defined performance level. Results of pushover analysis were used to identify the top drift when masonry walls reached respective performance level and which is depicted in Figure 31.

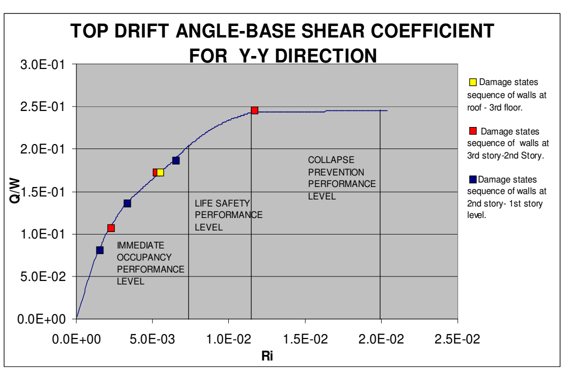

Figure 4. Damage sequence of masonry walls

According to the defined performance level of building, all the masonry walls at first story level will be collapsed before the Immediate Occupancy Performance Level. All the masonry walls at second story level will reach extensive damage stage before the Immediate Occupancy Performance Level while it will reach complete damage state at the Life Safety Performance Level. However, masonry walls at third story level will be reached only slight structural damage state.

Subsequently, the engineering demand parameters (EDP) obtained from nonlinear response-history analysis were used to study the vulnerability of this structure. It was proven that the X-X direction of the building is the most vulnerable. It was observed that the maximum response story drift of the X-X direction in the second floor did not exceeded the life safety performance level for the suite of earthquake. However, it was not exceeded the immediate occupancy performance level in case of maximum response story drift for the suite of earthquakes on Y-Y direction and not even all the columns in the first story level did reach the extensive structural damage state. It was found that the behavior of the second story level is similar to that of first story level.

It was observed that the performance of the third story in both directions is significantly better than that of first and second story levels. The both, maximum response story drift and minimum median response story drift in X-X direction was lain within the life safety performance level while that of Y-Y direction was lain within the immediate occupancy level. It was observed that none of case, all the columns reached the slight structural damage state at third story.

6.LOSS ANALYSIS

Loss analysis was carried out only for structural elements and masonry walls because the cost of nonstructural elements and facility equipment are less compared to that of structural elements and masonry walls. Besides, simple calculation was done to determine losses rather than going for more rigorous analysis such as Montre Carlo type procedures because of time constraints.

The total structure repair cost of each case was calculated by multiplying the total repair quantity by the unit cost. The total repair quantity was estimated by identifying corresponding step of pushover analysis to story drift. It was observed that total structure repair cost would be between Rs.240,000.00 and Rs.2,500,000.00.The average total structure repair cost is Rs.2,337,550.00. However it was learnt that the total construction cost of this building is Rs. 16,000,000.00. Thus the average repair cost is 14.6% of total construction cost.

The variation of total structure repair cost of each case with direction of the structure was studied to identify which direction contributes most to the repair cost. The graphs of total repair cost versus direction and story are depicted in Figures 5.

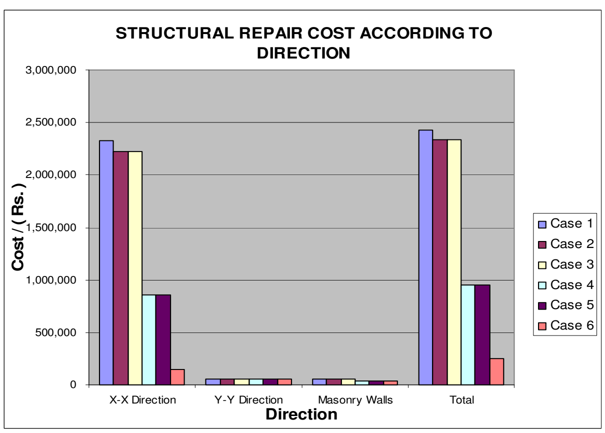

Figure 5. Structure Repair Cost According to Direction

7.CONCLUSION

In summary, much knowledge has been gained from the study performed for this report. The behavior of three storied reinforced concrete frame structure used as a school building located in SriLanka, exposed to seismic load was studied.

It was found that the seismic performance of this structure is very poor in X-X direction while that of Y-Y direction is adequate. Therefore, even a small magnitude earthquake posed a threat because of poor X-X direction of the structure. The threat present with the occurrence of small magnitude earthquake events would most likely cause extensive damage to the structure.

As per FEMA 356, Prestandard and Commentary for the Seismic Rehabilitation of Building, performance levels of this building were defined using results of pushover analysis. The performance levels were indicated in the graph of base shear coefficient versus top drift. Accordingly, the inherent weakness of X-X direction of the structure was illustrated in the performance levels also. Therefore, these facts lead to a retrofit of the structure and it can be considered as a obligation for future work.

The behavior of masonry walls was studied using analytical model in structural analysis. It was found that the walls located at first two stories reached the complete structural damage state at small story drift. However, the behavior of the masonry walls was not studied for in case of out of plane failure. The loss analysis was carried out for masonry walls also but the repair cost of the masonry walls are negligible compare to that of reinforced concrete structure.

The repair cost of each damage state was calculated based on the rates obtained from a private company in SriLanka. Therefore, total structure repair cost was determined for maximum and mean cases of suite of earthquakes. It was found that total structure repair cost in X-X direction would be Rs.2,,228,000.00 in case of mean response story drift in the X-X direction while that of Y-Y direction is only Rs.56,000.00.

Considering the above facts, the following suggestions can be made as concluding remarks. Reinforced concrete shear walls could be provided to enhance the shear capacity in the X-X direction of the building. Besides, it was found that the base shear coefficient in Y-Y direction is 0.25 and it is adequate even for soft-first story structure. In addition, it is necessary to strengthen the infill masonry wall because it was observed that the infill masonry walls reached complete structural damage state prior to the structure reach immediate occupancy performance level.

8.ACKNOWLEDGEMENTS

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