Fragility of Existing Building Structure Due to Floor Addition (Case: Grand Heaven Pluit Bulding Renovation, North Jakarta)

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Abstract. In earthquake-prone areas, buildings must be designed and constructed to withstand earthquake and gravity forces to avoid casualties due to disasters and minimise losses. The taller the building the greater the horizontal deflection that occurs on the upper floors, so tall buildings have a greater risk than low buildings. Fragility curves represent a function that relates the intensity of an earthquake to the probability of exceeding a certain damage limit. The fragility curve will provide a rational basis for evaluating the seismic risk of the structure. This study aims to evaluate the seismic risk of a building structure based on its fragility. The structure analysed is a funeral home in North Jakarta. The existing building has 8 floors before renovation and 10 floors after renovation. The existing structure uses a combination of shear wall shear resisting system. Nonlinear static pushover analyses were performed using seismoStruct software to obtain capacity curves. The three criteria used in determining the damage condition are HAZUS MH-MR, ATC-40, and Silva Criteria (2012). The probability obtained determines how likely the building is to experience structural failure.

Keywords: *Capacity Spectrum, Fragility Curve, Pushover Analysis, Seismic Performance Evaluation*

1. Introduction

The grand heaven building is a funeral home that serves funerals for all religions. In 2016, an 8 (eight) floor building was built for funeral processions and crematoriums. As time goes by and along with the increasing needs of funeral homes, renovations are carried out to increase space requirements, so that in 2020 it is planned to add 2 (two) floors. The addition of this floor, due to the need for a funeral room that is always full every day and many requests from customers to add new rooms so that the needs of the funeral room are always met. The addition of floors can increase the earthquake load and gravity load that must be borne by the structure [1]. If this change is not considered in structural planning, it can cause instability during an earthquake. The addition of two top floors can create additional stresses in the structure that can cause cracking or deformation in structural elements. This can damage the structural integrity which can be harmful to humans inside the building [2]. This paper aims to investigate the seismic performance of the building structure prior and after the renovation by means of its fragility curves.

In recent years, fragility curves have become important tools for various purposes related to earthquake risk management and resilience, including earthquake loss estimation, structural design, repair, earthquake insurance and business continuity [3] [4]. In the absence of sufficient empirical data, analytical and hybrid methodologies have emerged in the context of weakness and vulnerability curve analysis [5]. These curves show the probability of damage that exceed a certain damage state as a function of earthquake intensity during its service life. Asadi [6] suggests that excessive acceleration of seismic response is the main cause of damage.

Concept of fragility curve has recently emerged as a tool for estimating probability of structural damage due to earthquake s suggested by HAZUS [7], SYNER-G [8], and SELENA [8]. It is discovered that fragility curves are helpful instruments for forecasting the likely degree of damage. They enable the estimate of a level of damage probability for a specified ground motion index and display the likelihood of damage to building structures as a function of strong motion parameters. For more accurate earthquake damage prediction, the prediction procedure and vulnerability function should reflect the actual behavioral characteristics of the building. Gubana and Mazelli [9] classify the procedures for establishing seismic fragility functions into empirical, assessment, or analytical approaches.

Based on numerical simulation, an analytical method was used in this work to construct the fragility curves for the existing building both before and after refurbishment. Using the shear vs. strain and moment vs. curvature relationships of all cross-sections, the force-displacement relationship (capacity curve) at the top of the building structure (reference point) is obtained in the first step of the analytical fragility approach, which is the non-linear static pushover analysis of the structure. Once the capacity curve was obtained [10], then it might be converted into capacity spectrum expressed in ADRS format [11][12]. The damage ratio at each excitation level was then obtained by calculating the damage indices of the structure for each damage state at each excitation level. On a lognormal probability scale, fragility curves were then developed for each excitation level [13].

2. Methods

This research uses secondary data in the form of a structural model of the as build drawing which is already known the type of concrete quality, steel quality, so that the data used is in accordance with what happens in the field. The structural plan and section drawings of the building are shown in Figure 1 to Figure 3. The 3D building model of the structure is carried out using Building Modeller which has been incorporated with seismostruct finite element software in accordance with the as build drawing data. The loads acting on the structure consist of dead loads, live loads and additional dead loads. The calculation of dead load is done automatically from the seismostruct programme, while the additional dead load and live load are determined based on SNI 1727:2020. Related to earthquake loading, it is necessary to first determine the target displacement value of the building due to lateral loading. Target Displacement can be determined based on seismic action whose spectral response curve is obtained from the results of entering the value of Spectral Acceleration, Damping Percentage, Spectrum Type, Ground Type and Importance Class. However, if the user already has a target displacement value to be achieved beforehand, then the value can be entered manually, without going through calculations by the system. Furthermore, the user also needs to determine the Perfirmance Criteria of the structure. After that, running analysis can be performed. After the analysis, the values of displacement, base shear force, capacity curve shape, and performance limit based on material strain limit can be obtained.

The pushover analysis results are then processed to obtain the capacity spectrum and fragility curve. The fragility curve results from the two models can then be compared to evaluate the performance of the structures used. This approach benefits both from its simplicity and its excellent ability to describe the nonlinear behaviour of structures. On the other hand, fragility analysis is considered an effective tool in the risk assessment process associated with earthquake engineering [14].

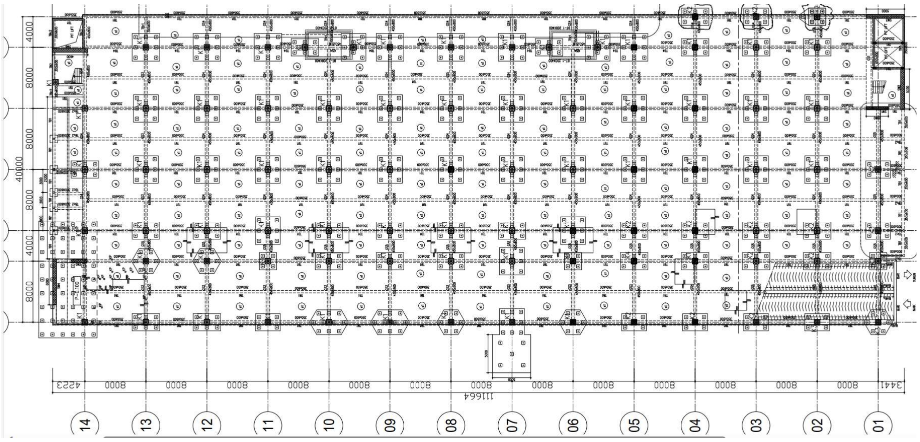

Figure 1 1st Floor Structure Plan

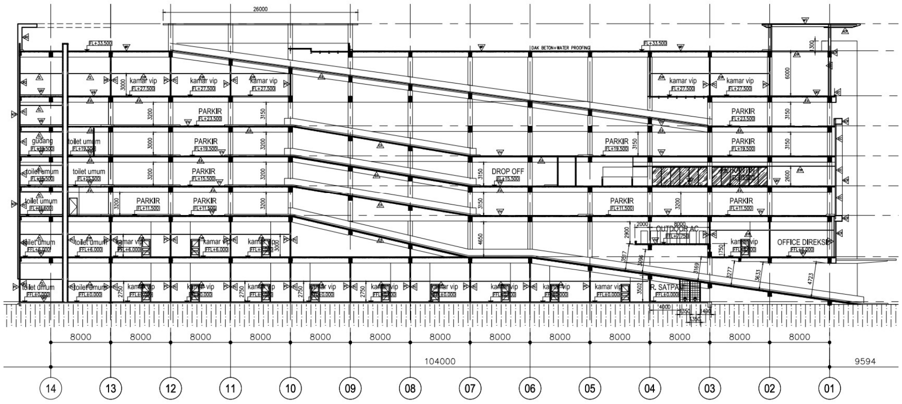

Figure 2 Section B of Grand Heaven Building Before Renovation

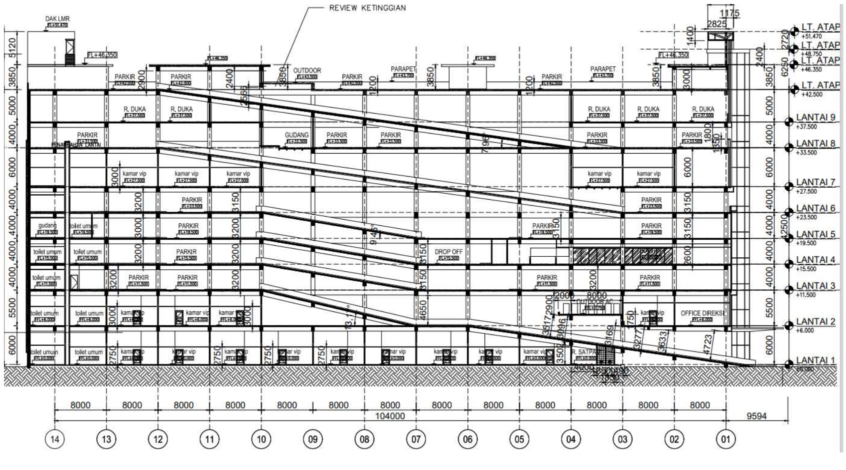

Figure 3 Section A of Grand Heaven Building After Renovation

The Grand Heaven Pluit building is one type of high-risk reinforced concrete frame building where the building is used as a Chinese funeral hall and also a funeral ceremony venue. The building has 8 floors before renovation and 10 floors after renovation. A cross-sectional image of the model is presented in Figure 4. The 3D model was created by adjusting the AutoCAD plans using Building Modeller in SeismoStruct.

The 3D modelling results of the building before renovation are shown in Figure 5, while the building after renovation is shown in Figure 6. The structural dead loads derived from elements such as columns, beams, floor slabs, shear walls are automatically calculated by Seismostruct. Table 1 shows the results of the dead load calculation due to the self-weight of the structure:

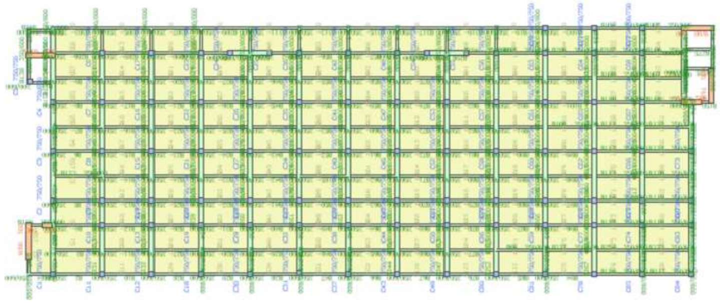

Figure 5 Plan of the Grand Heaven Pluit Building structure

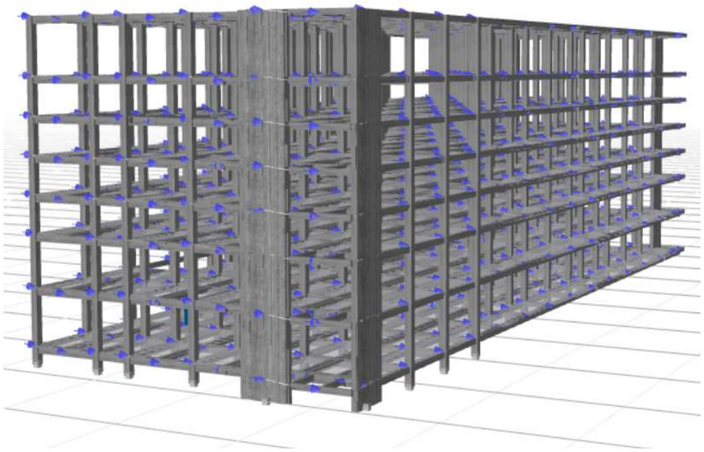

Figure 6 3D model before

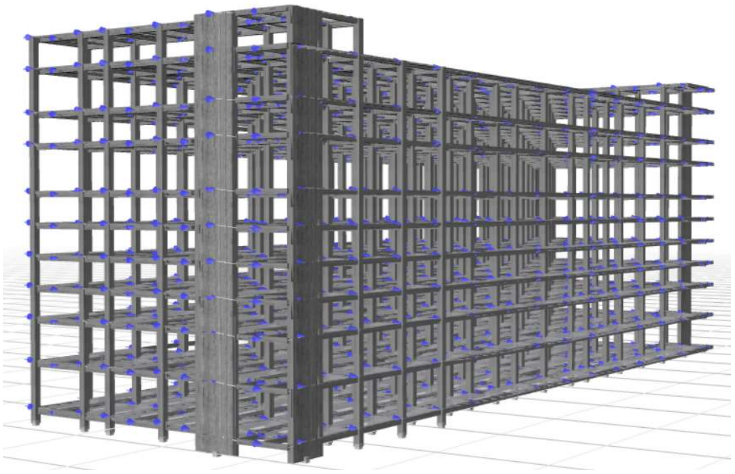

Figure 7 3D model after renovation

Table 1 Recapitulation of structural dead load per floor

Building Before Renovation		Building After Renovation	
Floor	Mass of the structure (kN)	Floor	Mass of the structure (kN)
Floor 1	11799,2	Floor 1	11799,67
Floor 2	11768,64	Floor 2	11768,64
Floor 3	10292,74	Floor 3	10292,74
Floor 4	9436,12	Floor 4	9436,12
Floor 5	9436,12	Floor 5	9436,12
Floor 6	8921,428	Floor 6	8921,428
Floor 7	9025,552	Floor 7	9025,552
Floor 8	9438,502	Floor 8	9438,502
Floor 9	[redacted]	Floor 9	10907,14
Floor 10	[redacted]	Floor 10	10701,61
Floor 11	[redacted]	Floor 11	1368,769
Total	80118,3	Total	104071,7

3. Results

3.1. Pushover Analysis Result

After conducting nonlinear static pushover analyses on the two modes that have been made previously, the results are obtained in the form of capacity curves that describe the relationship between the base shear force and the roof displacement value. The results of the capacity curves of the two models are shown in Figure 8.

In the model after renovation, numerical analysis with seismoStruct was only able to be carried out until it reached a roof displacement value of 1.1 meters with a Base Shear value of 66222.31 kN. Whereas in the model before renovation, the pushover analysis was successfully carried out until the target displacement of 1.1 meters with a Base Shear value of 49526.65 kN was achieved.

Based on the two graphs, it was found that the maximum value of the structure before renovation occurred at a Base Shear value of 80747.48 kN with a displacement of 0.36 meters. While in the structure after renovation, the maximum value is reached at a Base Shear of 62329.17 kN with a displacement of 0.42 metres.

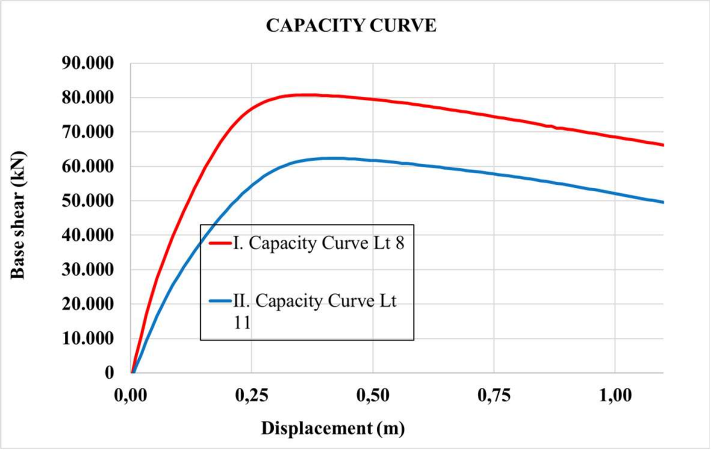

Figure 8 Model capacity curves after renovation and before renovation

3.2. *Capacity spectrum*

After obtaining the output in the form of base shear and displacement on the capacity curve, further data processing is needed to obtain the capacity spectrum in ADRS format. This capacity spectrum will later be used to form the fragility curves of the two structural models. The capacity spectrum in ADRS format shows the relationship between spectral displacement (sd) in meters and spectral acceleration (sa) in units of gravitational acceleration (g). The results of the capacity spectrum of the two models are shown in Figure 9. Based on these two graphs, it is found that the peak point in the capacity spectrum before renovation occurs at a value of 1.08 g with an Sd value of 0.26 meters. While in the capacity spectrum of the model after renovation, the peak point is obtained when Sa is 0.76 g and Sd is 0.29 meters. Figure 9 below shows a comparison of the capacity spectrum of the two models. If the capacity spectrum is smaller, it may indicate that the building has a lower capacity to bear earthquake loads or other lateral loads. The capacity spectrum is a graphical representation of the relationship between the earthquake acceleration (usually on the horizontal axis) and the force that the building structure can bear.

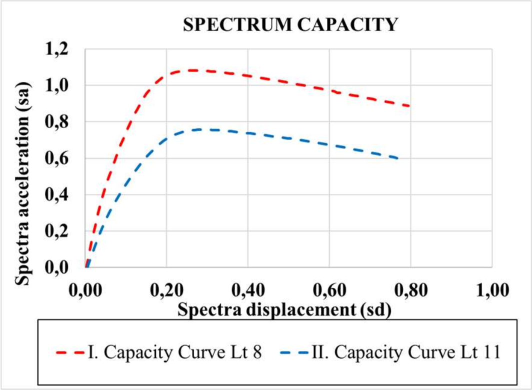

Figure 9 Capacity spectrum of the model after renovation and before renovation

3.3. *Fragility Curve*

Fragility curves show the probability of a structure exceeding a certain damage state as a function of a parameter that defines the earthquake intensity. This curve is used to estimate the seismic risk of a group of buildings with similar structural features. The fragility curve is formed using equation 1:

$$P[ds|S_d]= \phi[\frac{1}{\beta_{ds}}\ln\left(\frac{Sd}{S_{d,ds}}\right)] \quad (1)$$

which expresses the relationship between the probability values of exceeding a certain level of damage due to spectral displacement (Sd) occurring based on a multi-criteria damage situation. The probability calculation is performed iteratively for several spectral displacements ranging from 0.0 to 2.0 m, so that the probability points can be used to construct fragility curves. Each damage threshold calculates the probability of damage. In this study, performance limit values were used, which were determined based on 3 criteria: Hazuz MH-MR5, ATC-40, and silva.

1) Hazuz MH-MR 5 criteria

The results of the calculation of the probability of damage to the pre-renovation structural model and the post-renovation model using damage limits consisting of slight, moderate, extensive, and complete can be seen in Figure 10 below. Figure 10 shows the comparison of the fragility curves of the pre-renovation and post-renovation building models on the damage limit criteria by Hazuz MH-MR5. The probability value of each damage criteria in both models is almost the same. To illustrate the difference in probability values caused by the additional floor load, Table 2 shows what effect the additional load has. Table 2 shows that the probability of damage of the building model with the addition of floor loads is greater than that of the model before renovation. The decrease in probability values at the slight, moderate, extensive, and complete damage levels are 0.844%; 4.281%; 21.217%; and 49.55%, respectively.

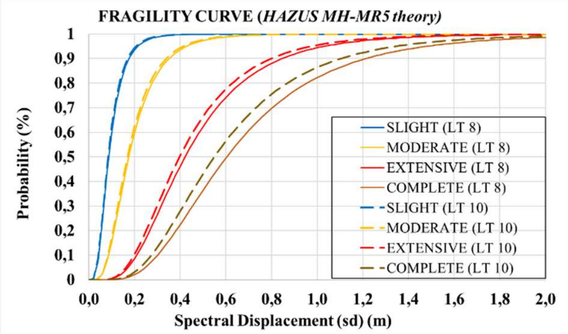

Figure 10 Fragility curve with criteria Hazus MH-MR 5

Table 2 Probability values at the Hazuz-MR5 Damage limit

Sd	Level of Damage	Probability	Percentage
0,2	Slight (8 Floor)	0,94	0,84
	Slight (10 Floor)	0,94	
	Moderate (8 Floor)	0,59	4,28
	Moderate (10 Floor)	0,62	
	Extensive (8 Floor)	0,08	21,22
	Extensive (10 Floor)	0,104	
	Complete (8 Floor)	0,021	49,55
	Complete (10 Floor)	0,026	

2) ATC-40 Criteria

The results of the calculation of the probability of damage to the damage limit consisting of immediate occupancy (IO), life safety (LS), and structural stability (SS) for the building model before renovation and the building model after renovation can be seen in Figure 11. Figure 11 shows the comparison of the fragility curve of the building model before renovation and the building model after renovation with the addition of two floors with the damage limit according to ATC-40. The probability values of the two models are almost the same for the immediate occupancy (IO) and life safety (LS) damage criteria, while the structural stability (SS) damage criteria show a clear decrease in the probability values of the two models. To see the percentage decrease in the probability value between the model before renovation and the model after renovation, table 3 can show the percentage decrease as follows. Table 3 shows that the probability of damage to the structural model with the addition of floors is higher than that of the structural model before the addition of floors. The decrease in the probability value at the immediate occupancy (IO), life safety (LS), and structural stability (SS) damage levels is 1.608%, 12.048%, and 59.696% respectively. At the structural stability (SS) damage level, the probability value decreased significantly.

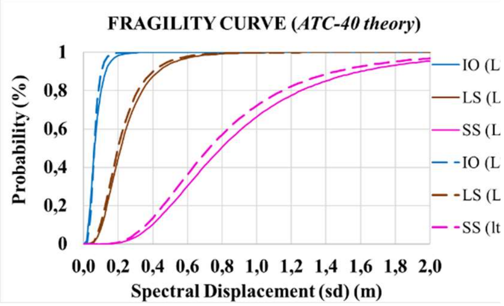

Figure 11 Fragility curve based on ATC-40 criteria

Table 3 Probability values at ATC-40 damage limits

Sd	Level of Damage	Probability	Percentage
0,2	IO (8 Floor)	0,98	1,61%
	IO (10 Floor)	0,99	
	LS (8 Floor)	0,44	12,05%
	LS (10 Floor)	0,50	
	SS (8 Floor)	0,0056	59,69%
	SS (10 Floor)	0,0102	

3) Silva criteria

The damage limits resulting from the calculation of the probability of damage to the model before and after renovation in Limit State 1, Limit State 2, and Limit State 3 are shown in Figure 12 below. Figure 12 shows the fragility curves of the unrenovated structural model and the renovated structural model based on criteria proposed by Silva (2012). The probability values of the two models are almost the same for limit state 1 and limit state 2, but for limit state 3, the probability values decrease significantly between the two models. Table 4 shows the degree of decrease in the probability value for each damage threshold. The table summarises the probability values of the pre- and post-renovation structural models during the addition of the second floor. Table 4 shows that the probability of damage occurrence in the building model with the addition of the second floor is greater than that in the building model before the addition of the second floor. The rate of decrease in the damage probability value at the damage level limit state 1 (LS1), Limit state 2 (LS2) and limit state 3 (LS3) is 4.457%, 18.83%, and 92.08%, respectively. Comparison of the fragility curves of the three criteria based on the percentage difference in displacement spectra value (0.2) metres on the building model before renovation and the model after renovation of the addition of two floors. First, the percentage value of Hazuz MH-MR5 criteria with 49.55% damage criteria, then ATC 40 criteria with structural stability (SS) damage criteria of 59.696%, and finally Silva criteria with limit state (LS3) damage criteria of 61.414%.

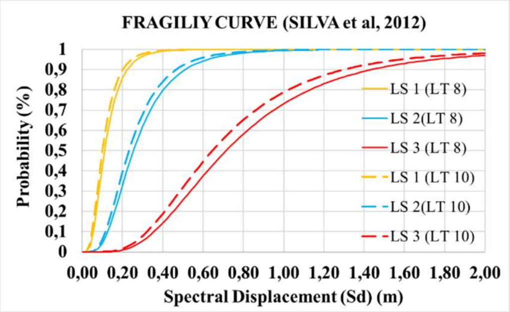

Figure 12 Fragility curve based on Silva (2012) criteria

Table 4 Probability values at Silva Damage Limit

Sd	Level of Damage	Probability	Percentage
0,2	LS 1 (8 Floor)	0,86	4,46%
	LS 1 (10 Floor)	0,89	
	LS 2 (8 Floor)	0,33	18,83%
	LS 2 (10 Floor)	0,39	
	LS 3 (8 Floor)	0,0096	61,41%
	LS 3 (10 Floor)	0,0156	

4. Discussion

Based on the results of the static loading analysis on the Grand Heaven Pluit building, North Jakarta, several discussions were obtained.

Capacity curve before renovation to shows higher base shear value than the capacity curve after renovation. This explains that the higher the height of a building can make the stiffness of a building decrease. Similar to Kumar's research [15] for higher storey buildings show lower ultimate spectral displacement compared to lower buildings. The additional floors can change the load distribution and affect the structural capacity of the building below. The initial elastic behaviour where the capacity curve has a small slope and even tends to be linear. Furthermore, the curve undergoes strain hardening (increase in strain), at this stage the structure has undergone plastic deformation so that if the increase in load continues to be added, the structure changes shape and cannot return to its original shape which in Figure 8 is marked by the line on the capacity curve graph experiencing a significant decrease. If the loading continues, the structure will collapse.

Fragility curve based on HAZUS MH-MR5, ATC-40, and silva (2012) criteria shows that the probability of collapse in the structure after renovation or 10-storey building is greater than the probability of collapse in the structure before renovation. So based on the difference in the value of the probability of damage of the two models to the same earthquake value, it can be stated that the addition of floor loads to the existing building is proven to reduce the performance of the structure in resisting earthquakes, besides that the addition of floors also makes the level of probability of damage greater. Nehe's research [2] shows that the taller a building is, the higher the plan earthquake force used. The overall structure with the addition of floors to the existing building shows that it can increase the stress ratio that occurs in structural elements so that the structure becomes less structurally strong. This is because the lateral load acting on the structure increases through the axial mechanism, so that it can add bending moments that occur in beams and columns. So that the building structure after renovation has a greater probability of damage.

5. Conclusion

Based on the explanation above, it can be concluded that the results of the fragility curve of the Grand Heaven Pluit Building, North Jakarta show that the 8-storey building has a higher stiffness than the building with 10 floors. Based on the difference in the probability of damage values of the two models against the same earthquake value, it can be stated that the addition of floor loads to the existing building is proven to reduce the performance of the structure in resisting earthquakes, besides that the addition of floors also makes the level of probability of damage greater.

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