# Comparison of building structure performance with masonry and without masonry

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**Abstract.** In structural designing, commonly the brickwall is only considered as a gravity load acting on the beam. On the other words, the wall in the building structure is assumed as a non-structural component. In this paper, the structural performance of a three-story building with masonry and without masonry due to seismic loads will be analyzed using pushover analysis by using the ATC 40 standard. The modeling of the building uses SeismoStruct software and assumed that the building is located in the earthquake ground acceleration region in Padang, West Sumatra. Based on the results of the analysis, the performance level of the three-story building with masonry is different compared to the building without masonry. The building with masonry as a structural component shows a better performance than without. This explains that the presence of masonry can contribute to the strength of the structure in receiving lateral loads such as earthquakes.

## 1 Introduction

Building structures generally consist of columns, beams, plat, and infill walls. In designing a structure, engineers generally do not consider the infill wall component as a structural component because the function of the wall is only considered as a non-structural component. In reality, infill walls such as bricks have strength, and stiffness, and tend to interact with the portal when exposed to large lateral forces. This is evidenced by cracks in masonry that transfer loads from the portal to the brick wall in various cases of buildings due to the seismic. However, in the planning of a structure, the masonry wall is taken account only as a gravity load acting on the beam .

Walls are the structures that surround an area, support floors and roofs, or divide a building's floor space into the required number of rooms. Any suitable material, such as brick, stones, wood, concrete, aluminium, steel, can be used to create the walls. They are necessary to offer convicts seclusion and to shield them from the environment.

Although it is widely understood that the behavior of a structure with walls will be very different due to earthquake forces compared to a frame structure, the strength of masonry is still commonly ignored. This is because there are still no regulations governing by the stakeholders. Meanwhile, the analysis of masonry buildings has been widely investigated where previous studies have shown that earthquake loads affect the seismic response of masonry build-ings. This is due to several factors such as the quality of the bricks used, the relation-ship between the masonry, the durability of the bricks, the irregularity of the structure, and the characteristics of the ground motion [1]. Maidiawati et al states in theirs research that he experimental results showed that most specimens exhibited an increase in their lateral strength, secant stiffness, deformatio capacity, and energy dissipation. Brick buildings are currently very widely used for housing and offices. In addition, high-seismic countries such as Italy have developed theories, and numerical and experimental analyses to reduce the vulnerability of brick buildings.

In this paper, the influence of a three-story building with masonry and without masonry due to seismic loads will be analyzed using pushover analysis with the ATC 40 method. The building modeling uses SeismoStruct software with the assumption that the building is located in the earthquake ground acceleration region in Padang, West Sumatra.

Padang is known as the riskiest area in the world regarding the earthquake, since this city lies on a dangerous fault. In the Sumatra area the plates meet in a subduction zone, where the boundaries of the Indian plate are forced beneath the Australian plate. The plates are sliding northeastward at about 7 cm per year and dipping under the Sunda plate, which encompasses Sumatra and Singapore [2, 3]. The city is one of the disaster-prone areas in Indonesia due to its territory lies within one of the world's most active fault lines namely the "Ring of Fire" [1]. One of the major earthquakes that affected Padang includes the Mw 7.6 earthquake which occurred off the island of Sumatera, near the city of Padang on 30 September 2009. The epicenter of the earthquake was located about 57 km west of the low-lying city of Padang and at a sea depth of 71 km [4].

In some areas, most of the damaged buildings caused by earthquakes were residential houses. The damages

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affect the number of casualties and socio economic losses. Most of residential houses in some countries are made of masonry walls. Because of the material cost and simple construction method, concrete brick masonry walls become widely used in Indonesia.

### 1.1 Criteria for seismic resistant structures level

Earthquake planning of earthquake-resistant building structures uses the concept of Performance Based Earthquake Engineering (PBEE) which is a method for designing, evaluating, designing, and monitoring engineering facilities whose performance is below the target and the given seismic response. The performance of structures based on ATC 40, which is a reference for performance-based planning, the category of earthquake-resistant structural criteria can be seen in Table 1 and Figure 1.

**Table 1.** Performance leve based on ATC 40.

| Performance level | Interstory drift limit |
|---|---|
| Immediate Occupancy (IO) | ≤ 0.01 |
| Damage Control (DC) | 0.01 – 0.02 |
| Life Safety (LS) | 0.02 – 0.033 |
| Struktural Stability (SS) | > 0.033 |

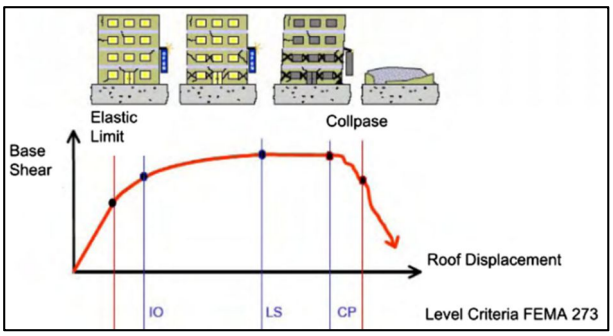


**Fig. 1**. The level of performance description.

### 1.2 Non-linear static pushover analysis

Non-linear pushover static analysis aims to find the capacity of a structure. The analysis is carried out by applying a load in the lateral direction whose value is increased gradually (incremental) proportionally on the structure until it reaches the target displacement or reaches a mechanism on the verge of collapse due to the occurrence of plastic joints in beam and column elements. In nonlinear procedures, demand and capacity are two things that need to be understood to get good structural performance .

Furthermore, pushover analysis is a static analysis method that is commonly employed for the design of earthquake resistant buildings and bridges. This method involves applying a series of lateral loads to the structure, gradually increasing in magnitude until the structure reaches its ultimate capacity. Pushover Analysis allows engineers to assess the strength and deformation capacity of a structure, helping them make informed decisions about the design and reinforcement of critical components.

Demand is a representation of the building's response spectrum due to subgrade movements that occur. While the capacity curve is a curve of the relationship between the base shear force (Vb) and the displacement of the roof floor point (Δrooftop) which is the ability of the structure to the load that occurs. The performance point is obtained when the capacity of the structure can handle the desired response spectrum demand[5]. The capacity spectrum method is a method where finding the performance point is done by reducing the elastic response spectrum to intersect with the capacity curve in the Acceleration Displacement Response Spectra (ADRS) spectral coordinates as shown in Figure. 2.

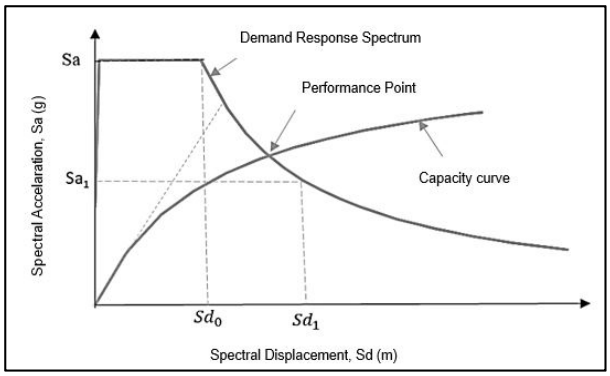


**Fig. 2.** Capacity spectrum method.

To convert the capacity curve into spectral coordinates using the following equation.

$$Sa = \frac{v}{\frac{w}{\alpha 1}} \quad (1)$$

$$Sd = \frac{\Delta roof}{PF1\phi roof} \quad (2)$$

where v, w, $\alpha 1$, are modal mass, mode participation factor and modal amplitudo at rooftop respectively for the first mode (k=1). Next the response spectrum graph, having axes Sa and T has to be converted using the relation in ATC 40.

$$Sd = \frac{T^2}{4\pi^2} Sa \quad (3)$$

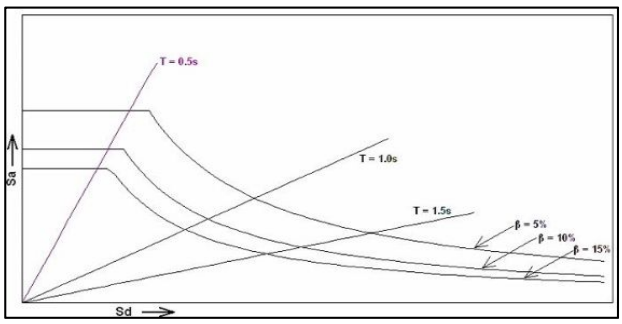


**Fig. 3.** ADRS representation of the Response Spectrum curve.

### 1.3 Masonry buildings

Masonry wall systems are building systems that use masonry materials such as brick, stone, or concrete blocks to construct walls. These materials are typically stacked on top of each other and held together with mortar.Masonry is the oldest building material that still finds wide use in today's building industries. The most important characteristic of masonry construction is its simplicity. Laying pieces of stone, bricks, or blocks on top of each other, either with or without cohesion via mortar, is a simple, though adequate, technique that has been successfully used ever since remote ages. Naturally, innumerable variations of masonry materials, techniques, and applications occurred during the course of time. The influence factors were mainly the local culture and wealth, the knowledge of materials and tools, the availability of material, and architectural reasons [6].
Masonry is the oldest technique used for constructing buildings or structures. This kind of buildings, specifically stone masonry, provides strength, and durability to the structure and also controls indoor and outdoor temperatures. Even reinforced masonry also resists hurricane and seismic forces.Masonry has been used as the construction material for several thousand years and still, and it's popular.

The benefits by using brick walls are for an instance are their durability and longevity. They can withstand harsh weather conditions, including extreme temperatures and moisture, without deteriorating.In addition, bricks are non-combustible and provide excellent fire resistance. This can be a crucial safety feature in buildings, especially in areas prone to wildfires or where fire safety is a significant concern. Brick walls have good sound insulation properties. They can help reduce the transmission of sound from one side of the wall to the other, providing a quieter indoor environment. Brick walls have high thermal mass, meaning they can absorb, store, and slowly release heat. This property helps in regulating indoor temperatures, leading to energy efficiency. It can contribute to lower heating and cooling costs over time.Also they require relatively low maintenance. They do not rot, warp, or corrode, and they resist damage from pests. This can result in cost savings over the life of the building.Many people find brick walls aesthetically pleasing. They can add a timeless and classic look to a structure and are available in various colors and textures, allowing for design flexibility. Bricks are typically made from natural materials such as clay and shale, making them environmentally friendly. Additionally, their durability means they have a long lifespan, reducing the need for frequent replacements and the associated environmental impact.

Earthquakes in some areas caused a number of buildings being damaged. Almost all of them were residentialhouses made of unreinforced masonry structure walls. These residential houses are generally known assimple houses. They are commonly built without structural design processes, so they could be classified as nonengineering structures. The damages greatly affected the number of casualties and socio economics losses. The wallswere made of brick and concrete blocks. xperiences showed the quality of the house walls are often varied due todisparities of materials and workmanship. Some typical disparities are poor quality bricks and poor quality of joints.Several reports have identified out-of-plane failure of walls especially unreinforced masonry walls as one of the dominant modes ofdamages and. This suggests that out-of-plane unreinforced masonry walls may be vulnerable to futureearthquake and therefore they should become a priority to improve the performance and seismic resistance to reduce losses.

## 2 Methodology

The building analyzed in this study is a three-story building with a height of 9 meters. The location of the building is assumed to be in Padang, West Sumatra. The building is 9 meters high with a column size of 400x400 mm and a beam size of 400x500 mm. The materials used are concrete quality 30 MPa, longitudinal reinforcing steel quality 420 MPa, and transverse reinforcing steel quality 300 MPa. Building modeling using SeismoStruct software with masonry and without masonry can be seen in Fig. 4 and 5. For location, its assumed that the building is in Padang. Most of Indonesia is located in earthquake areas with moderate to high intensity, therefore, earthquake-resistant structural analysis is very important. One of them is Padang city which is located in the province of West Sumatra. Geographically, West Sumatra Province is located on the west coast of the island of Sumatra, which is an earthquake-prone area because it is locate between two active plates of the world.

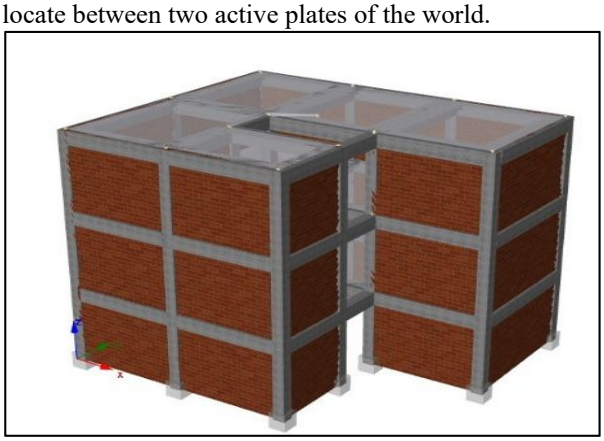

**Fig. 4**. Masonry building modelling.


**Fig. 5**. Without masonry modelling.

Location is needed to define the suitable respons spectrum for earthquake loading. The earthquake response spectrum is a plot of the maximum response of all possible single-degree systems to a given ground motion. The response spectrum is used as a dynamic approach to structures, especially earthquake-resistant structural planning and lateral force calculations.

The structure must be assigned a seismic design category. In this analysis, the building functions as an office so according to SNI 1726:2019 (Indonesian Earthquake resistants structure code), the seismic design risk category belongs to risk category ii. The seismic load on the building with masonry wall and building without masonry wall models is the response spectrum with 3 types of soil site classes namely hard soil (Sc), medium soil (Sd), and soft soil (Se) located in Padang, West Sumatra [-0.5616° latitude, 100.2141° longitude]. The response spectrum graph can be seen in Figure. 6.

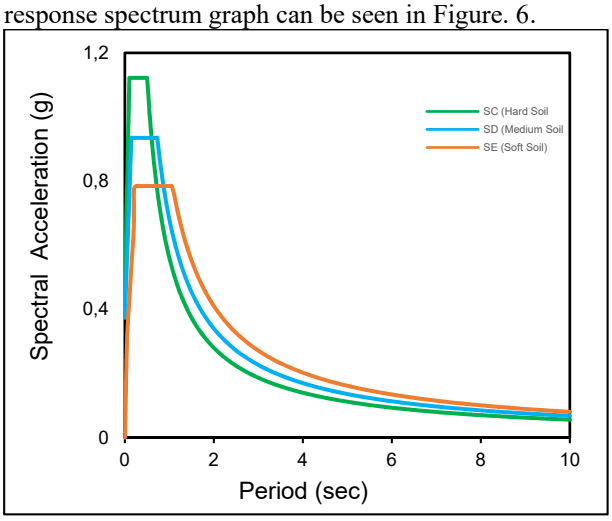


**Fig.6.** Response spectra of Padang.

A response spectrum is a graphical representation of the peak or steady-state response of a structure to a range of harmonic input frequencies. It is commonly used in structural engineering and earthquake engineering to assess the dynamic response of structures subjected to various ground motion inputs.Response spectra provide valuable insights into the dynamic behavior of structures under seismic loading conditions. Engineers can use this information to optimize designs, identify potential weaknesses, and ensure that structures meet safety and performance criteria in seismic-prone regions.

The pushover analysis in this analysis was carried out with SeismoStruct software for building with masonry wall and building without masonry wallmodels by inputting the seismic shear force value at the center of mass of the building. The seismic shear force value is determined by multiplying the seismic response coefficient (Cs) with the total weight of the building (Wt). The value of the shear force can be seen in Table 2.

The term "lateral earthquake load" refers to the horizontal forces that act on a structure during an earthquake. Earthquakes generate ground motion, and this motion can exert lateral forces on buildings and other structures. These lateral forces are often the most critical aspect of seismic loading because they can lead to structural deformation, displacement, and damage.

**Table 2.** The distribution of lateral earthquake load.

| Soil type | Coefisien seismic (Cs) | Weight (kN) | Base shear (kN) |
|---|---|---|---|
| Hard soil (SC) | 0.140 | 42521.645 | 596.445 |
| Medium soil (SD) | 0.117 | 42521.645 | 497.037 |
| Soft soil (SE) | 0.038 | 42521.645 | 159.437 |

Pushover analysis was performed with a target displacement of 1/50 of the building height based on the terms and conditions of inter-story allowable deviation [5]. The first stage of pushover analysis was conducted in both the x-axis and y-axis directions to obtain the seismic capacity of each model. the second stage is to compare the shear capacity of the building with masonry wall and building without masonry wall models.

## 3 Discussion

Pushover analysis result shows the capacity curve of x and y direction. X and Y direction can be seen in Figure. 4.The capacity curve or pushover curve represents the nonlinear behaviour of the structure and is a load-deformation curve of the base shear force versus the horizontal roof displacement of the building. Pushover analysis transforms a dynamic problem to a static problem

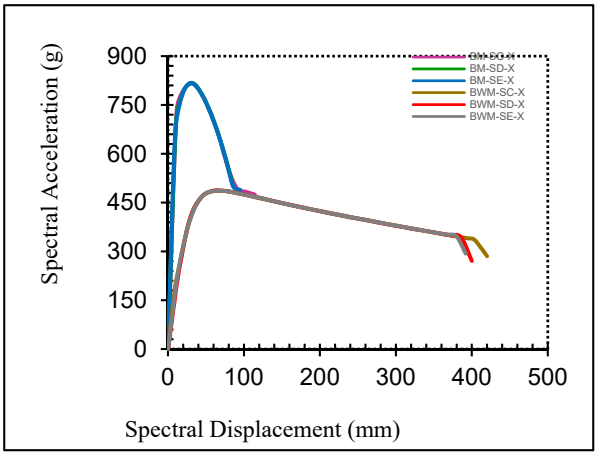


**Fig. 7**. Capacity curve x-direction.

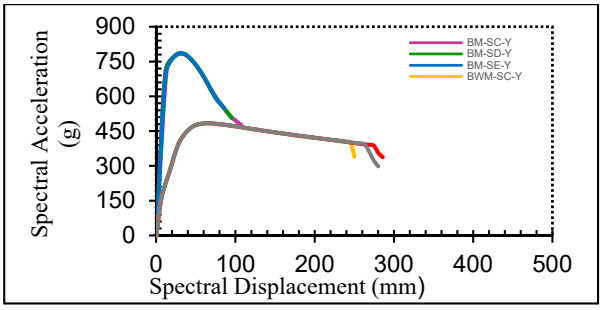


**Fig. 8.** Capacity curve y-direction.

The relationship between the base shear (g) with displacement (mm) is presented in Fig. 7 and 8. Based on the result, the capacity curve of building with masonry wall is higher and tends to be upright than the capacity

curve of building without masonry wall. The slope of the capacity curve shows the stiffness of the structure building structure. The curve that tends to be upright shows that building has a higher stiffness value than a sloping capacity curve.

Figure 7 and 8 show that the building with masonry wall of x and y direction the same displacement, while the building without masonry wall has a more extended displacement in the x-axis than the y-axis.the intersection result of the capacity curve and spectrum demand is obtained perfromance point value. Performance point values based on the ATC 40 method in x and y direction is presented in Table 3.

**Table 3.** Performance level.

| Type building | Axes | Drift ratio | | | Performance level |
|---|---|---|---|---|---|
| | | Type soil | | | |
| | | SC | SD | SE | |
| Masonry | x | 0.00127 | 0.00119 | 0.00106 | IO |
| | y | 0.00149 | 0.00132 | 0.00119 | IO |
| Non masonry | x | 0.00317 | 0.00317 | 0.00272 | IO |
| | Y | 0.00278 | 0.00381 | 0.00254 | IO |

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From Table 3 above, it can be seen that the drift ratio value of building with masonry wall is smaller than building with masonry wallw for the three type soils. The percentage difference between building with masonry wall and building without masonry wall in the x-direction for type SC is 1.5%, for type SD is 1.7%, and for type SE is 1.6% while the percentage difference between building with masonry wall and building without masonry wallin the y-direction for type SC is 0.9%, for type SD is1.9%, and for type SE is 1.1%.

The immediate occupancy performance level corresponds to low damage in a structure and small reduction on lateral stiffness and strength. In this study, the structures show immediate occupancy (IO) for all soil type used in analysis.

In other words, immediate occupancy refers to a building or structure being immediately available for use and occupancy once construction is completed. In the context of building design and construction, achieving immediate occupancy is a goal that signifies the structure meets certain safety and functional criteria, allowing it to be occupied by its intended users without delay.

## 4 Conclusion

Current seismic structure design generally follows a strength-based approach. Observed damage andBuilding collapses during recent earthquakes have raised concerns regarding the comfort of using these devicesapproach. For confined masonry (masonry with vertical tie columns and tie beamsalong the walls on the floor) the use of performance based design is quite promising. Construction with masonry is widely used inworld, and considering that the regulations used still prioritize strength as a design concept, engineers are starting to apply the performance based design concept to this type of building.

Based on the results of the pushover analysis that has been carried out for the three-story building with masonry and without masonry, the performance level of the building with masonry is smaller than the building without masonry. This explains that the presence of masonry can contribute to the strength of the structure in receiving lateral loads such as earthquakes. Although the difference in performance level is not too large, it is influenced by the low-rise level of the building, and the dimensions of the beams and columns used are also quite large. Therefore, the difference between the strength and stiffness of masonry and without masonry in this study does not have a significant effect.

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