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Seismic Risk Evaluation of Community Mosques in Southern Malang to Assess Their Suitability to Support Disaster Response

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ABSTRACT

In Indonesian culture, mosques are mostly built by local communities. Through time, these local communities develop a sense of belonging to the mosques they built. Mosques then become more than a place of worship. During hard times such as disasters, these mosques often become a place to seek help and protection. However, many times in disasters such as an earthquake, which occur rapidly and unpredictably, these mosques were unable to carry out their socio-cultural functions because of their own severe damage following the disaster. Therefore, this paper discusses the results of a seismic risk evaluation of 100 community mosques in the southern area of Malang Raya, one of the earthquake-prone areas along the southern coast of Java. The evaluation focussed on structural, architectural, and spatial aspects of the mosques based on field observation and visual documentation such as photographs and as-built drawings. One of the findings of this study is that the majority of the mosque buildings are gravity-only structures and unlikely to be earthquake-resistant. On the other hand, some architectural and spatial aspects of the mosques show some thoughtful considerations for their roles as places for the evacuation process and disaster support during emergency situations.

Keywords: *Community mosque, disaster response, earthquake, rapid evaluation, seismic risk*

1. INTRODUCTION

The majority of mosques in Indonesia are community mosques built by local people. These local communities develop a strong sense of place attachment with their mosques. This sense of belonging make these mosques more than just a regular place of worship. One of the socio-cultural significances of community mosques is their role to provide refuge during hard times such as conflicts and emergencies, as well as a place for evacuation and rehabilitation in times of disasters such as earthquake, flood, fire, etc. For example, the Humanity Road in their Situation Report (28 September – 2 December 2018) on the 2018 M7,5 Indonesia Earthquake identified the Internally Displaced Persons (IDPs) at Great Mosque Darussalam Palu's courtyard and Kolakola Village Mosque's courtyard [1] through their aerial photographs. People seek protection in their mosques during and after disasters due to pragmatic and socio-religious reasons.

Nevertheless, instead of protecting people during the emergency circumstances, the mosques frequently became the ones that were ruined by disasters, especially earthquakes, where vast destruction often happened in a blink of an eye. Earthquakes are disasters that occur fast and unpredictable, often resulting in serious damage to vulnerable the buildings. Even when they are not completely ruined, in many cases the mosques are not safe enough to function as emergency shelter.

Some serious damage might result in mosques' lack of safety as a place for evacuation after the disaster. Community mosques were often built incrementally, sometimes without comprehensive planning and overview from the first phase of their construction. There are also a lack of consideration for lateral or horizontal forces from disasters such as tornado and earthquake. In addition, there might no adequate supervision during construction from competent institutions.

A rapid assessment conducted by Puslitbang Perumahan dan Permukiman Kementerian PUPR on buildings and infrastructures in Pidie Jaya after an earthquake in December 2016 described that many mosque buildings in the affected area experienced collapse and severe structural damage [2]. Similarly, a series of earthquakes in Lombok from July to August 2018 caused major structural damage to many mosques [3]. One such building, sustained damage to its moment frames damage that led to a soft story even pancaking the building (Fig. 1). Several serious damage of mosque buildings also occured after an earthquake in Palu, Sulawesi Tengah, September 28th 2018 [4].

Figure 1 A mosque with severe damage after an earthquake in Lombok, August 2018 [3]

Studies on the resilience of contemporary public and residential buildings related to earthquakes are mostly carried out from a civil engineering perspective, especially detailed assessments of possible structural failure of the buildings in earthquake-affected areas. One study on the vulnerability of mosque buildings after earthquake was carried out by Pradono [5]. Another engaging study on post-earthquake structural assessment was conducted by Sobaih and Nazif [6] who proposed a methodology to evaluate the seismic risk of some affected school buildings by various earthquake events in different countries. Researchers in this field of study emphasize technical aspects of building structures. Furthermore, although examinations have been carried out frequently on public and residential building damage after an earthquake, it is important to carry out preventive actions by evaluating community mosques, especially in the earthquake-prone areas.

In the field of architecture study, academic research related to earthquake mainly focuses on traditional houses and their resilience to earthquakes, e.g. the behavior of Joglo houses against earthquakes [7], the structure and construction of 'Pencu' Houses in Kudus [8], earthquake-resistant construction of traditional houses of the Besemah tribe in Pagaralam, South Sumatra [9], and the structure of traditional Batak houses against earthquakes [10]. Little architecture research has been conducted on contemporary vernacular architecture such as community mosques in earthquake-prone areas, especially from a preventive viewpoint to evaluate their structural, architectural, and spatial design aspects relevant to potential earthquakes in the region.

Thus, an evaluation is needed in the field of architectural study to understand the common failures in the structural, architectural, and spatial design aspects of community mosques regarding their capability to resist earthquake and to function as a place for evacuation. Therefore, this research has been conducted in the form of in-situ and ex-situ rapid visual assessment on the built mosques based on the field observation and visual documentation such as photographs and as-built drawings was conducted in a hundred built mosques. Based on Andrew Charleson's book, 'Seismic Design for Architects: Outwitting the Quake' [11], several structural features can be identified and then visually analyzed in the existing buildings. Therefore, relevant structural, architectural, and spatial aspects related to seismic performance were chosen for this study.

Four common structural elements, i.e. (1) number of floors, (2) type of main structure (e.g. beams and columns), (3) roof structure, and (4) minaret structure, were recorded so that the general typology of mosque structures can be identified to evaluate potential structural deficiencies, i.e. (1) potential soft-story, (2) short columns, (3) slender columns, (4) heavy roofs/overhangs, (5) potential pounding effect, (6) absence of seismic force resisting systems (shear wall, braced frames, or moment frames), and (7) potential topographic effect.

Apart from the structural aspects, some architectural and spatial aspects were also analyzed. This is due to the close relationship between the structural aspects and the overall design aspects. In the Earthquake-Resistant Design Concepts by FEMA-P 749, configuration and regularity are among the requirements in the seismic design concepts. Some nonstructural components and systems are also considered important in an earthquake-resistant design concept [12]. Therefore, five architectural aspects related to the seismic context were chosen, i.e. (1) mosques' spatial arrangements, (2) mosques' spatial configurations, (3) void – solid balance of the vertical elements (walls), (4) void – solid balance of the horizontal elements (upper floor), (5) the building's exit route and accessibility. Finally, five spatial aspects of the community mosques were also chosen for this study, i.e. (1) mosques' open space, (2) surrounding area's open spaces, (3) buildings' separations from surrounding buildings, (4) accessibility of the mosques, and (5) distance from the Southern Coast.

Overall, various methods in seismic vulnerability evaluation can be classified into qualitative, quantitative, and hybrid methods [13]. One of the frequently used methods is developed by FEMA-P 154, namely the rapid visual screening of buildings which is based on the visual observation mainly on buildings' exterior elements [14]. Similar seismic risk evaluation on the built structures was conducted by Albayrak et al. in 2015, where a large scale in-situ investigation of more than a thousand buildings was undertaken. Their method was a rapid street screening for potential seismic hazards to detect, create an inventory, and rank the most vulnerable buildings in a forthcoming earthquake [15]. They focused on the structural aspects and used a scoring technique for each structural criterion in order to detect the most vulnerable buildings in the area.

On the other hand, this study aims to evaluate the common deficiencies in structural, architectural, and spatial aspects of mosques in order to generate some applicable preventive strategies. These strategies are focused on their applicability on the existing mosques and are intended to be useful as design considerations for the future mosque buildings in a similar context. However, our evaluation is not comprehensive. This study do not look at torsional, diaphragm, and some other potential structural weaknesses due to insufficient data gathered regarding those aspects.

This rapid visual evaluation was conducted on a hundred mosques in the southern area of Malang Raya, popularly known as Malang Selatan (Southern Malang). It is one of the earthquake-prone areas along the Southern Coast of Java Island. It is within a subduction zone prone to volcanoes and earthquakes.

The first phase of the evaluation was data gathering through field observation and documentation of the community mosques and their surroundings. During this phase, a checklist containing all aspects of evaluation was filled out. The second phase was identifying the typology of mosque structures. The third phase was analyzing the structural, architectural, and spatial aspects of mosques. Each mosque was evaluated by two researchers using the distribution analysis of each aspect as well as contingency analysis between aspects considered related to each other. The fourth phase was the triangulation process through some discussions regarding the possibility of different findings from the field observation and the third phase analysis to gain validity of the research findings. The fifth phase is interpreting the findings and generating preventive strategies based on the result of this evaluation.

2. THE STRUCTURAL TYPOLOGY OF COMMUNITY MOSQUES IN SOUTHERN MALANG

Of the total mosques studied in this research, 81% have one floor and 19% have two floors. All of the mosques studied had reinforced concrete structure as the main structure (beams and columns) of the building (Fig. 2). However, there are variations in the roof structure with 56% using a reinforced concrete roof (flat slab and dome), 31% using a wooden roof structure (*tajug*), and 13% using a combination roof structure of reinforced concrete and wood, or reinforced concrete and steel. Furthermore, 88% do not have minarets, 10% have reinforced concrete towers and 2% have steel towers. Figure 3 summarizes the structural typology of the studied mosques.

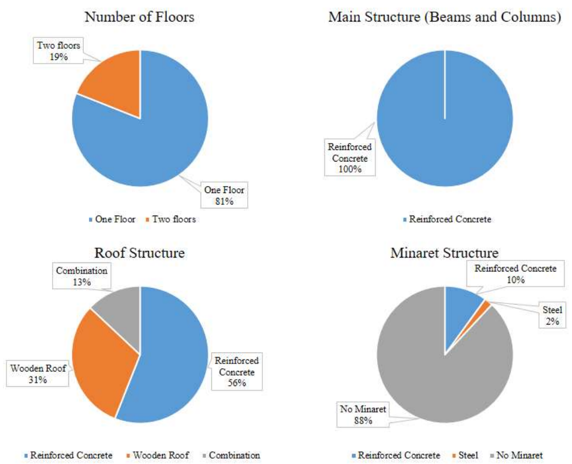

Figure 2 The distribution of structural elements of studied mosques

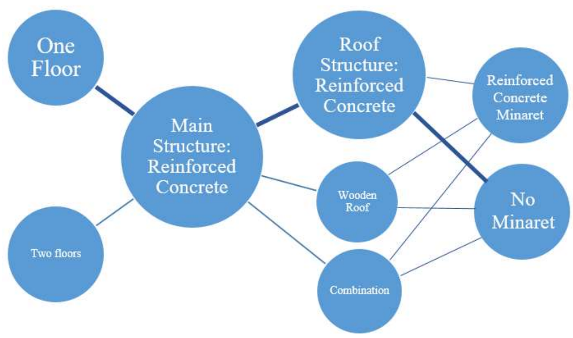

Figure 3 The structural typology of the studied mosques

3. EVALUATION OF THE STRUCTURAL ASPECTS OF THE MOSQUES

The structural aspects analyzed in this study are (1) potential soft-story, (2) the presence of short columns, (3) the presence of slender columns, (4) the presence of heavy roofs/overhangs, (5) potential pounding effect, (6) the absence/presence of seismic force resisting systems (shear wall, braced frames, or moment frames), and (7) potential topographic effect. Figure 4 is an example of the seismic risk visual screening on one of the studied mosques.

Figure 4 The seismic risk visual screening of a mosque

The first structural aspect analyzed is the potential or possibility of a soft-story failure occurring in the mosque building. A soft-story can occur because the stiff and strong upper floors due to masonry infills, the columns in one story longer than the ones above, or discontinuous columns. A soft-story can also occur due to the presence of weak columns and strong beams [11]. Based on our evaluation, 49% of mosques have a soft-story potential. It was a surprise to find some single story mosques (mosques with only one floor) have a soft-story potential due to their multiple flat slab roofs and domes. Of the one story mosques, 38.3% have a soft-story potential. Meanwhile 94.7% of two-story mosques have a soft-story potential because the upper floors and roofs are commonly more massive than those of the ground floor. Figure 5 summarizes the structural aspects of the studied mosques.

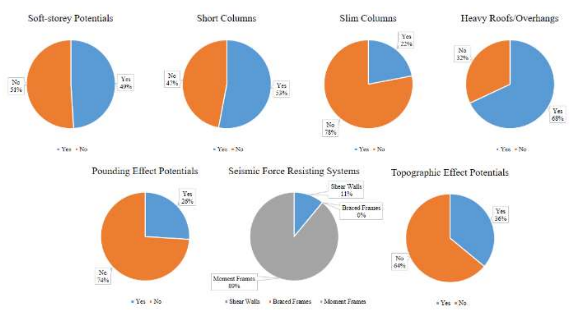

Figure 5 Distribution of the structural aspects of the studied mosques

The second aspect analyzed was the existence of short columns. Short columns in buildings can be caused by the presence of mid-story height beams so that some columns become shorter than the others. A ribbon/strip opening at the top of an infill wall in the moment frame structure can also cause short columns [11]. 78.9% of two-story mosques and 46.9% of one-floor mosques have short columns (Fig. 6).

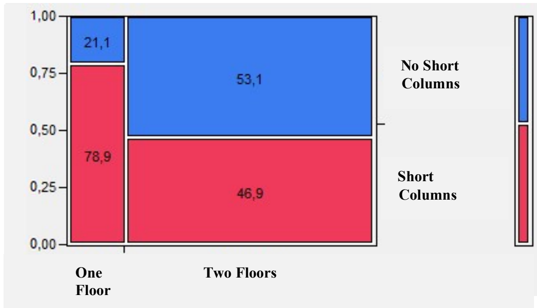

Figure 6 Contingency analysis of short columns by number of floors

In the two-story mosques, the existence of short columns is due to the difference in column height at one series of moment frames on the ground floor or the difference with the column height of the floor above. Meanwhile, in the one-story mosques, most of the short columns are those that support the multilevel flat roofs and domes. There are also short-columns that occur due to the infills and ribbon/strip windows in one and two stories mosques.

The third aspect is the presence of slender columns. The slender columns found in the mosques studied were long columns (two stories height) without any mid-height beams in both directions but with the similar dimensions as the regular columns around them. 22% of the studied mosques have slender columns. Slender columns were found on 22.2% of the one-story mosques and 21.1% of the two-story mosques. Most of the long columns found were in the interior of the buildings, supporting the dome or *tajug* roof, standing right from the ground floor to the roof without any mid-height beams (Fig. 7).

Figure 7 Some examples of the long and slender columns with no mid-height beams

The fourth aspect is the presence of heavy roofs and/or overhangs. 68% of the studied mosques have heavy roofs and/or overhangs. 84.2% of two-story mosques and 64.2% of one-story mosques have heavy roofs and/or overhangs (Fig. 8). The presence of heavy roofs and/or overhangs in one-story or two-story mosque buildings is due to the large number of concrete slabs (sometimes in two or three tiers) and domes used (Fig. 9).

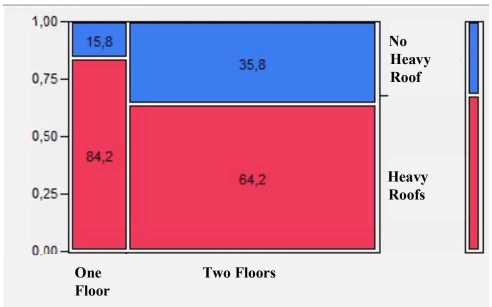

Figure 8 Contingency analysis of heavy roofs/overhangs by number of floors

Figure 9 Some examples of heavy roofs/overhangs in one and two story buildings, sometimes combined with short columns supporting a concrete dome

The fifth aspect is the potential pounding effect caused by insufficient separation gaps between buildings, especially in two-story mosques as well as the minarets that are placed adjacent to the mosque buildings. 26% of mosques have a potential pounding effect during an earthquake. The potential pounding effect on these mosques is due to the relatively narrow distance between the mosque buildings and the surrounding buildings. 70% of mosque buildings with minarets have a potential pounding effect when a large earthquake hits.

The sixth aspect analyzed is the type and presence of the seismic force resisting systems. 89% of mosque buildings only use moment frames, while 11% are also equipped with shear walls on some parts of the building. Even though moment frames have been used extensively, the strength and reinforcement detailing of columns and beams in some mosques need to be examined further regarding their earthquake resistance. In addition, the presence of slender columns and short columns in these mosque buildings has resulted in the inconsistencies within a series of moment frames, which can increase the vulnerability of the building during an earthquake.

Figure 10 An example of the masonry and concrete infill walls as a seismic resisting element

The seventh aspect is the possibility of a potential topographic effect on mosque buildings. A mosque building located on a sloping site has the potential for topographic effect during an earthquake, especially those with a steep slope. 36% of the studied mosques were built on the sloping sites. However, the possibility of a topographic effect during earthquake in several mosques may have been reduced by the presence of retaining walls and efforts to flatten the surface of the sites. Further examination is needed on the quality of the retaining walls, so during an earthquake the retaining walls are strong enough to hold the buildings above.

Figure 11 An example of mosque built on a sloping site with some short columns and discontinuous columns

Based on the seven structural aspects analyzed, majority of the studied mosques are gravity-only structures instead of seismic resistant structures. Figure 12 is the result of contingency analysis that summarizes structural aspects of the mosques. In some mosques, the potential for a soft-story is strengthened by the presence of short columns, slender columns, and the heavy roofs/overhangs. However, in the majority of mosques commonly two to three deficiencies were found.

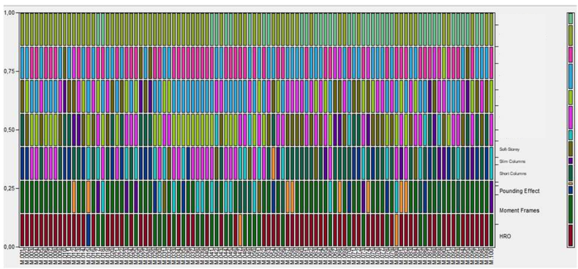

Figure 12. Contingency analysis of mosque codes by various structural aspects

4. EVALUATION OF ARCHITECTURAL ASPECTS OF THE MOSQUES

The architectural aspects analyzed in this study are (1) mosques' spatial arrangements, (2) mosques' spatial configurations, (3) void – solid balance of the vertical elements (walls), (4) void – solid balance of the horizontal elements (upper floor), and (5) the building's exit route and accessibility. These architectural aspects may have an impact of some structural considerations, such as the irregularity of columns and beams, or the absence of sufficient seismic force resisting systems due to the openness of building faćades. Figure 13 is the result of distribution analysis of architectural aspects of the studied mosques.

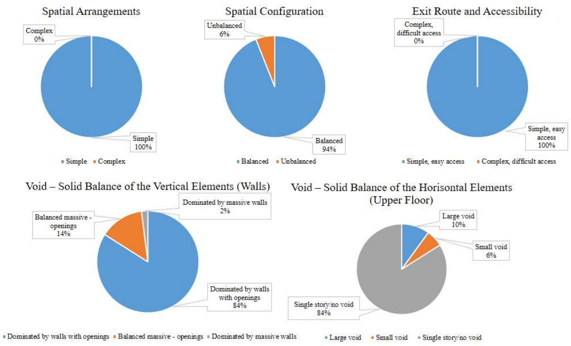

Figure 13 Distribution of architectural aspects of studied mosques

The first architectural aspect analyzed is the connection between the main rooms and the circulation area within the building (spatial arrangements). We investigate whether these rooms are directly connected to the circulation path (hallway, terrace, balcony, or corridor) in a straight or simple way, or are there complex room arrangements (rooms within rooms) before being connected to the main circulation path. Overall, the studied mosques have a simple connection between their rooms and their circulation path. Most of the rooms in the mosques were directly connected to the hallway, terrace, balcony, or an open corridor (Fig. 14).

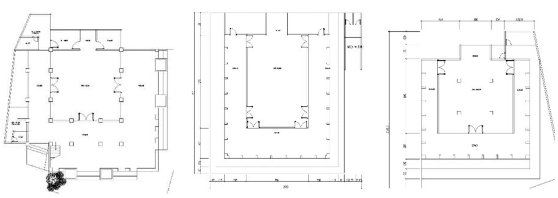

Figure 14 Some examples of the mosques' floorplan with the simple connection between main rooms and the main hallway

The second aspect is the spatial configuration of the building. This aspect evaluated whether the placement of rooms in the mosques formed a balanced (symmetrical and semi-symmetrical) or unbalanced (asymmetrical) spatial configuration. 94% of mosques have balanced spatial configurations. A balanced or symmetrical spatial configuration would resist horizontal forces in the building without inducing serious torsion effects and simplify the arrangement of the structural elements. However, there are several considerations, such as the shape of the sites and the incremental process of building a mosque, which result in unbalanced spatial configurations (Fig. 15).

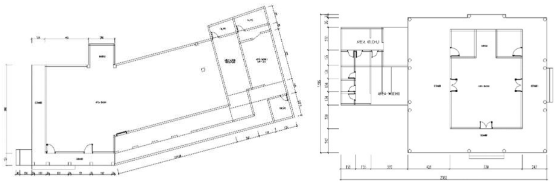

Figure 15 Some examples of the mosques' asymmetrical spatial configurations

The third aspect analyzed is the balance of voids and solid vertical elements (walls). Mosque architecture is well known for its openness, which is marked by many openings on the walls, especially on the main prayer hall of the mosque. 84% of mosques have walls with openings (doors, windows, lattices, etc.) that are more dominant than their massive walls (walls without openings). 14% of mosques have a balance between massive walls and walls with openings. Only 2% of the mosques are dominated by massive walls. The massive walls in the mosques are usually located at the *mihrab* side of the mosques.

The fourth aspect is the ratio of voids and solid horizontal elements (floors and roofs). The elements observed are voids on the upper floor of the mosque buildings. The presence of large voids is sometimes, although not always, accompanied by high walls with columns and beams only in one direction. In addition, in the void area sometimes there are also columns in a series of moment frames with removed beams for aesthetic reasons. This can increase the vulnerability of the buildings during a major earthquake, due to the uneven stiffness of the moment frames. 10% of the mosques have a relatively large void, while 6% have relatively small or narrow voids compared to the total area of the second floor. Most of the mosques studied (84%) were single-story mosques without voids, or two-story mosques, but the lower floors were used as service areas, so they did not have any void to the floor above.

Figure 16 Some examples of a large void in the studied mosques where the columns in the high wall at the *mihrab* side only has one direction beams

The fifth aspect is the exit route and accessibility of the building. This section evaluated the exit route as well as the placement of stairs and circulation elements of the buildings. Overall, the mosques have a quite simple accessibility and exit route. The doors of the main prayer hall are usually located on almost every side of the room. The building circulation elements such as stairs, doors, hallways, and corridors are also easy to find (Fig. 17). Most corridors and balconies are connected directly to the open space outside the building.

Figure 17 Examples of mosques with a simple access and easy-to-find circulation elements

5. EVALUATION OF SPATIAL ASPECTS OF THE MOSQUES' ENVIRONMENTS

The spatial aspects analyzed in the environment of the mosques are (1) the open space of mosques, (2) the open spaces of surrounding area, (3) the separation of mosques from their surroundings, (4) the accessibility of mosques and surrounding areas, and (5) the distance from the Southern Coast. Figure 18 is the distribution analysis of spatial aspects related to earthquake evacuation.

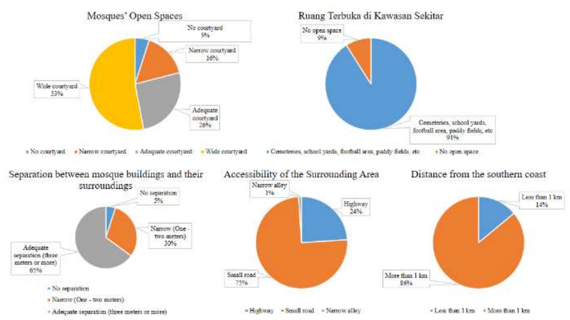

Figure 18 Distribution of spatial aspects of the studied mosques

The first and the second aspects analyzed were the presence of open spaces at the mosques' site and on the surrounding area. As much as 53% of mosques have a wide courtyard (the width of the yard is more than the height of the building), and 26% of the mosques have an adequate courtyard (the width is equal to the height), and 16% of mosques have a narrow courtyard (the width is less than the height). Only 5% of mosques have no open courtyard at all. Meanwhile, 91% of the surrounding area of the studied mosques have various kinds of open spaces, and only 9% of the surrounding area which do not have any open spaces. The types of open space in the area around the mosques are quite diverse. Most of them are not in the form of city parks or open plazas, but in the form of soccer fields, school yards, rice drying fields, cemeteries, or even sugar cane and corn fields. However, these open spaces have a great potential to support the disaster mitigation process because of their large size as a safe gathering point in the area (Fig. 19).

Figure 19 Some examples of mosques with a large open space outside the building

Based on our analysis, 87.5% mosques that do not have any courtyard still have an open space in their surrounding area. The absence of the open space needs further attention if the mosque is to have a role as a place for disaster evacuation for their respective areas. The absence of adequate open areas results in the absence of sufficiently safe areas to gather people during an earthquake, and reduces the flexibility of the post-earthquake disaster emergency response.

The third spatial aspect analyzed is the physical separation between the mosque building and the surrounding buildings. 65% of the studied mosques had an adequate separation gap (three meters and more) from the surrounding buildings. 30% of mosques have a narrow distance (only one to two meters) from the surrounding buildings, and 5% of mosques have no separation between one or two sides of their buildings and their neighbors. A wider gap does mean the mosque is less likely to be affected by the neighboring building collapsing. However, to prevent the pounding effect, a far smaller gap is sufficient.

The fourth aspect studied is the accessibility of the area by road to where the mosque is located. Most of mosques (75%) are located on small roads, while the remainder are located on main roads or highways. Only

1% of mosques are located in an alley. Good accessibility to the surrounding area supports the role of mosques in the disaster response process.

The fifth spatial aspect is the distance between the location of the mosque and the coast. 89% of the mosques in Southern Malang area were located more than one kilometer from the South beach. 14% of the mosques were located less than one kilometer from the South beach. The mosques that are located adjacent to the South beach need a serious attention, because apart from facing the potential for earthquakes, these mosques also face the potential for sudden tsunamis due to tectonic earthquakes in the Indian Ocean. However, a more relevant measure on the elevation of the mosque is needed, because high mosques even near a beach might not be affected by tsunami.

Overall, the spatial aspects of the community mosques in Southern Malang have qualities that support their roles as safe places for the disaster evacuation, especially regarding aspects of availability of open spaces as safe gathering points and the accessibility of the mosques to their surrounding areas.

6. PREVENTIVE STRATEGIES TO REDUCE SEISMIC VULNERABILITY TO MOSQUES OF SOUTHERN MALANG

Based on the analyses of structural, architectural, and spatial aspects of the community mosques in Southern area of Malang Raya, the structural aspects require most attention since the seismic design failures are likely found in these aspects. Therefore, the strategy of strengthening building elements without dismantling the existing structure completely, known as retrofitting is deemed appropriate. "The purpose of retrofitting is to reduce the vulnerability of a building's inhabitants and the building itself – its structure, non-structural elements and possibly its contents to earthquake damage." [11]. One thing that needs to be underlined is, "A successful retrofit scheme usually not only improves seismic performance but enhances functional and aesthetic building qualities." [11].

Therefore, several applicable retrofitting strategies which are in accordance with the function and aesthetics of the mosques as well as in line with the habits and common building traditions in the South Malang region are suggested as follows:

1. On the *mihrab* side, these walls are potential shear walls because most of them are more massive than the walls on the other three sides of mosque buildings. These walls need reinforcing to meet the requirements of shear walls in the seismic resistant building standards.
2. On the other three sides, the walls are usually more open. Therefore, additional strength could be provided by adding two small shear walls on the side which is parallel to the *mihrab* wall. Meanwhile, on the other two sides, walls that are not parallel with the *mihrab* wall, some braced frames or regular moment frames can be added. Or, perforated walls with typical mosque ornamentation patterns penetrations. Therefore, the mosque building would not seem closed from the outside.
3. Masonry infill walls that are too wide without sufficient reinforcement need to be divided with practical columns to stabilize them. Infill walls with strip or ribbon openings along top sides also need to be modified to prevent the presence of short columns.
4. Inconsistencies or irregularities in moment frames that occur frequently need to be improved by adding side columns and/or mid-height beams, or by modifying the existing structural elements to strengthen the whole structure.
5. Lighter upper structures and materials need to be considered whenever a mosque is planned to be significantly renovated. The replacement of heavy concrete domes with more lightweight domes, for example, has been done in many mosques nowadays. Masonry infill walls for the upper floors could also be replaced with perforated walls and mosque ornamentation patterns made of lightweight materials.

Apart from these five strategies, other strategies can be taken into considerations by community mosques' stakeholders. In the future, the construction of all community mosques should follow the Indonesian Codes of building safety, and therefore can be used for civil defence purposes. However, in the midst of the challenging situations, there are many options for creativity for architects and civil engineers to find new strategies to designing seismic resistant mosques. As Charleson states, "Although special requirements of seismic structure must be met and might constrain some architectural intentions... any negative influences may often be avoided by timely and creative structural configuration." [11]

7. CONCLUSIONS

Based on the evaluation that has been carried out on the structural, architectural, and spatial aspects of community-based mosques and their environments in the South Malang area, it can be concluded that most of the mosques can be classified as gravity-only structures instead of seismic resistant structures. Unfortunately, they yet have not showed adequate considerations for horizontal or lateral forces during an earthquake. On the other hand, architectural and spatial aspects evaluated in these mosques have shown some thoughtful considerations for the mosques' roles as places for disaster evacuations. In the design process of future community mosques, all these three categories of structural, architectural, and spatial aspects need to be integrated into one unified design.

Further research into seismic resistant buildings in the field of architecture is still wide open. There are mosques and other vernacular buildings such as houses and schools in other regions with a similar context (earthquake prone area) but with different building customs or traditions. Due to some technical and non-technical limitations, our study is not yet comprehensive. A more detailed and comprehensive assessment including the torsional, diaphragm, and some other potential structural weaknesses that cannot be analyzed visually need further interdisciplinary studies combining several aspects of seismic vulnerability.

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