

Indonesian Architecture and Earthquake Vulnerability: the Development of Building Safety through the Civilization

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Abstract. Please let the above author information blank for the first submission of this paper to maintain anonymity during double-blind review process. If your paper is accepted, you will be required to submit the final (camera ready) version in which a completed author information as exemplified above must be provided. You should leave 8 mm of space above the abstract and 10 mm after the abstract. The heading Abstract should be typed in bold 9-point Arial. The body of the abstract should be typed in normal 9-point Times in a single paragraph, immediately following the heading. The text should be set to 1 line spacing. The abstract should be centred across the page, indented 17 mm from the left and right page margins and justified. It should not normally exceed 200 words.

1 Background

Indonesia is the largest archipelago country that consists of five major islands and about 30 smaller island groups. Altogether there are 17,508 islands of which about 6,000 are inhabited. The archipelago is on a crossroad between the Pacific and the Indian oceans, and bridges two continents of Asia and Australia (Fig.1). Its strategic position and fertile nature of the land have always influenced the cultural, social, political and economic life of the country through its civilization. Not surprisingly, it has a great variety of architectural styles which are unique such as traditional Javanese, Minangkabau, Toraja and others. Different types of traditional styles which are complemented by Chinese, Hindu, colonial, modernist, and post-modernist architectural influences are flourishing the islets.

Along fault containing magma that creates series of volcanic mountains ring of fire is the most geological feature spreading along 5000 km trough western coast of Sumatera, Java Island, Nusa Tenggara, Maluku, and up to Sulawesi with 132 active volcanoes. This geographical condition leads some 20 earthquakes to rock various parts of Indonesia every day, leading to a total of about 7,000 subterranean movements each year. Of that number, only about 60 are felt. In the period of 1779 -2010, the amount of earthquake that occurred exceeds 4,800 with the magnitude of more than 4.0 [1]. This natural condition is hazardous for the high-density population such as Java Island which is inhabited by 65% of 250

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million Indonesian populations. Some earthquakes turned to disasters such as a 7 SR earthquake in Pacitan and Yogyakarta that killed over 500 people in 1867 [2]. While in 1943, the Java earthquake turned 2.800 houses as debris and 213 fatalities, and lately in 2006 more than 156.000 houses destructed and more than 5.700 fatalities [3].



Fig. 1. Map of Indonesian archipelago of Nusantara

The building failures under an earthquake are always related to the architecture since the building integrity is defined by its form, material, and construction. Indonesian architecture is the archipelago style called as *Rumah adat Nusantara* under the tropical environment which depends on the resources of nature and civilization of the people. The concepts of Indonesian architecture is broad and extremely complicated with influences from many essential cultures, ranging from India, China, and the Middle East to the countries of the West while the vernacular architecture is also highly diversified from every ethnic perspective [4]. Indonesian architecture today covers from classic or traditional, vernacular, and modern buildings. The classical or traditional buildings are mostly characterized by old principles based on written and ancient vocal techniques. The vernacular houses are mostly utilized by most ordinary people affected directly both by the tradition and the new ways in the construction. The new-modern architecture in Java is affected directly by the global technology such as the use of fabricated materials and technique. The overwhelming mixed techniques between the old and new ways related to the use of materials, especially the introduction of the Portland Cement, and their suitability with the local tradition and environmental climate initially happened from the time of the Dutch colonialism in the 17th century [5].

To discover how the building development considers the risk of nature, we assessed three periods of the civilization in architecture which are the classics or tradition, the influences of Islamic mission and Western colonialism, and also the post-independence era. Architectural features related to earthquake consideration are essential in this discussion. By this method, the precaution on earthquake vulnerability in every period will be identified, and the mitigation of building failures under earthquake can be solved in more appropriate manners.

2 Result and Discussion

2.1 Indonesian traditional architecture and a classical earthquake synchronization

The most famous classical Indonesian architecture is a tower-like temple called Candi which as commonly constructed in the era of the Hinduism and Buddhism in Java. These temples are mostly built in the form of a pyramidal roof by stone or terracotta bricks, elevated in absolute level, and decorated with ornaments and relics as the story or message of the religious teaching. The pointed roof as a representation of the mountain, which was the legendary Mount Meru as the residence of the gods, is the primary purpose of the architecture. These principles now still can be found in most of the temples in Java such as Borobudur or Prambanan which represent Buddhism for the former and Hinduism for the latter. These two religions had flourished before the introduction of Islam [6]. However, other architectural heirloom beside the temples is very limited since the domestic buildings were constructed from wood and bamboo. The materials of the structural construction decided the style of architecture rather than the concepts for the appearances [7].



Fig. 2. Traditional Architecture in Indonesia [8]

In the other side, the traditional architecture of the houses in Indonesia instigates from two sources; from the custom of Indian Hinduism as well as Buddhism which affected Java Island deeply, and from the local traditional architecture pre-dating the Hindu and Buddhism era. The oldest traditional houses in Indonesia recently are only about 150 years old since they were constructed from perishable wooden materials. However, some of the relics on the 9th century of temples in central Java describe how the domestic architecture of the ancient time was made, and they are similar with the contemporary vernacular forms which are still being utilized today. The Indonesian vernacular architecture represents

building tradition can be found in the archipelago of Southeast Asia and some parts of the continent. Distinguishing features of those houses include a stilt-house used for elevating the living floor, a very incline pitched roof and constructed from wood and other organic materials.

The traditional Indonesian house is a distinctive style which is unique to each ethnic group in Indonesia which are rooted by Austronesian ancestry. They share many characteristics such as timber construction, varied and elaborated roof structures, and supported by pile and beam construction. The house provides a primary space for the family and its community. Natural materials such as timber, bamboo, thatch, and fiber are used for the houses. Hardwood is usually used for piles, and a combination of soft and hardwood is utilized for the upper non-load bearing walls. The thatch material for the roof is mostly from coconut, sugar leaves, palm leaves, grass, and rice straw.

The traditional dwellings have developed to respond to natural environmental conditions, particularly Indonesia's warm and wet tropical climate. Indonesian traditional vernacular homes are commonly built on stilts except for Java, Bali, and the South-eastern Islands. A raised floor is aimed for allowing breeze to expel the warm and humid tropical air; to elevate the dwelling above storm water runoff; to allow houses to be built on rivers and wetland margins; to keeps people, goods, and food from dampness and moisture; to lifts living quarters above malaria-carrying mosquitos; and to avoid termites affected the house's materials.

Some of the more significant and distinctive houses can be found for instance Batak house in North Sumatra with boat-shaped roof, the Minangkabau of West Sumatra build the *Rumah Gadang* with a distinctive multiple gables, the homes of Nias with massive ironwood pillars with towering roofs, the Riau region is characterized by villages built on stilts over waterways. Javanese houses are not built on piles, and also Balinese homes are a collection of individual, mostly open structures. The Sasak people of Lombok build pile-built bonnet-roofed rice barns that are often more distinctive and elaborate than their houses. Dayak people who traditionally live in communal longhouses built their houses on piles which exceed 300 m in length. The Toraja of the Sulawesi highlands is renowned for their *Tongkonan*, houses built on piles and dwarfed by massive exaggerated-pitch saddle roofs. *Rumah adat* on Sumba has distinctive high thatched roofs and are wrapped with covered verandahs. The Papuan such as Dani with *Honay*, the small family compounds composed of several circular-domed huts, or Kurowai with very high tree house thatched roofs (Fig.2).

Almost all of the houses are built with wooden and organic materials in every island of the archipelago and laid on stilts. Timber materials are abundant in a tropical country which gives lightweight and flexible structure, less thermal mass, and replaceable construction. Lightweight building mass is always suggested for low rise building in a high-risk area to avoid the effect of overturning moments and multiplying energy of an earthquake by the wave resonance [9]. Furthermore, a lightweight wooden structure will create a flexible or low displacement of the building after a stroke since the system will back to the original position easily compared to the heavyweight materials. The timber poles are utilized as the primary structure to elevate the function loads from the ground level. Since the ground is mostly wet soil, the elevated floor is a necessity in the houses especially in western and northern parts which are more humid rather than eastern and southern zones of the archipelago. In opposite, the Javanese, Balinese, and South-eastern islands houses are mostly constructed without stilts but with elevated ground floor instead.

The stilt house is useful not only to avoid the wet soil but also acts as a pile foundation to put the structure stable down to the appropriate layer of the soil since the surface soil is mostly soft. In the case of *Rumah Gadang* in West Sumatra or *Rumah Lamin Dayak* Central Borneo, the piles are prolonged to the primary structure of the house above [10], [11]. In

other cases such as *Rumah Nias* or *Rumah Batak*, the stilts are used as a foundation for an overhead separated system [12], [13]. Both the continuing and discontinuing pile system make the buildings perform effectively under an earthquake but be unlikely in the way they deal with the loads. In the case of continuous or integrated piles with the primary system, the stiff structure will be obtained with mostly bigger elements for the mainframe. Building integrity will be achieved by fixed based on the pile foundation with the flexible connection on the top. On the other hand, the discontinuous stilts will release the impact by the pinned joint between the pile and the primary column above. In this relatively simple connection, a more flexible structural system is achieved, and smaller or lighter elements may be utilized to eliminate the excessive weight of the structure (Fig.3).

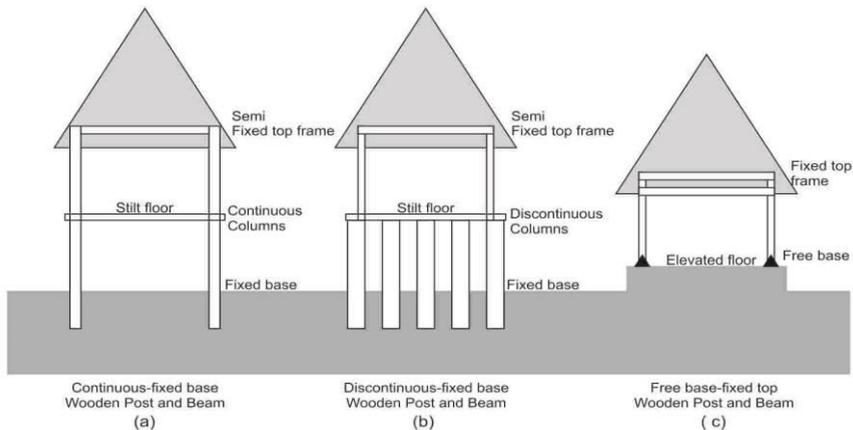


Fig. 3. The distinctive way of the traditional structural system to deal with earthquakes for (a) *Rumah Gadang* or *Rumah Lamin* (b) *Rumah Nias* or *Rumah Batak*, and (c) *Rumah Joglo* or *Pendapa Bali*

Non-stilt foundation such as used in Javanese or Balinese house is similar with the discontinuous stilt house except the use of stone for the foundation. Instead of elevated on stilts, the Javanese or Balinese and also Sumba house in the south-eastern regions of Indonesia are laid on the simple-stone bases. It could be understood that these areas are relatively drier and the soil is harder compared to the western lands. Piles foundation to reach the firm layer of the soil is not needed, but the higher elevation is still needed to avoid tropical floods and access a wind breeze for achieving the thermal comfort inside the house. To face the lateral force and to maintain the accepted structural stiffness, the simple pin connection in the base is accompanied by the reinforced frame with the additional element on the top of the system such as the additional layer of beams as *Tumpangsari* in the case of Javanese house.

2.2 External influences on the architecture and impacts on earthquake vulnerability

Most of the external aspects have influenced the Indonesian architectures are Islam and the Dutch colonial in the pre-independence era. Islamic civilization in Indonesia was initiated in the 13th AD by appearing of Islamic kingdom Pasai at Northern Sumatra in 1292. Two and half centuries later Islam spread to Java mostly through trading with relatively less political forces compared to other areas. Islamic architecture in Indonesia presented mostly in their mosques, king palaces, and tomb monuments [6]. Majapahit (1253-1527 AD) was the last Hindu period of Javanese history which rich with a series of magnificent temples and monuments. The New Age of Islamic influenced the north-coastal architecture such as

the mosque of Demak, Kudus, and Banten the 16th AD. The royal graveyard of Yogyakarta and Surakarta in Imogiri by the 18th AD are also found following the similar concept. Though Islam had broadly flourished, it is believed not to introduce new physical forms instead. The quick spread of Islam over the Hinduism and Buddhism culture, unfortunately, triggered a syncretism both in the philosophical and physical aspects including architecture. Islamic form then customized the tradition of Hinduism and Buddhism Ideas in Java [7]. However, the scale of the grand mosques was still demanding an innovation to deal. The four central columns system was constructed without the *Tumpangsari* as used in houses but was alternated with the additional post and beam system surrounding (Fig.4).

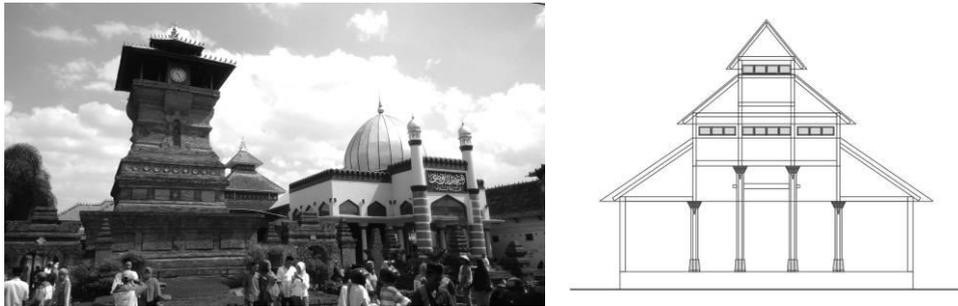


Fig. 4. The Grand mosque of Kudus with classical three roof layers on the main prayer hall, Hindu style of the drum tower, and Islamic style front hall (left) and the section of the main building (right)

The spread of Islam through the region introduced architectural influences which are more ideological rather than technological. Islam was not introducing a whole tradition in building technique but synchronizing of the existing architectural forms to accommodate the Muslim requirements. The Kudus mosque tower *Menara Kudus*, built in the 14th-century at Majapahit era on the north coast of Java, resembles a *Candi* which was adapted for use as the drum for *azan* time. Most of the earliest Indonesian mosques synchronized the existing buildings and their tradition in Java and Indonesia such as the utilization of the pyramidal roof supported by the four central columns *Sakaguru* which attributed particular symbolic significance in both the vernacular and Islamic structure.

Because of earthquakes, the Islamic public building such as grand mosque of Demak, Kudus, or Yogyakarta resembled the *Joglo* house which is based on the four central columns of *Sakaguru* without the additional beam layer *Tumpangsari*. The surrounding-additional post and beam support the central system acting as buttresses. Under the lateral force, those buttress system keeps the primary structure which is very tall away from excessive displacement. In the case of the Yogyakarta earthquake in 2006, the Yogyakarta Grand Mosque was affected less with some vertical displacement of about 6 degrees while many other buildings were damaged and collapsed. The wooden buttress system supporting the four central columns was hardly found before surrounding the archipelago except for the grand mosques.

Western influences were starting in 1509 when the Portuguese and followed by other western colonials started to dominate the Indonesian Archipelago though Marco Polo from Venice came earlier for trading and turned to control the enormously lucrative spices in 1292. The Portuguese, Spanish, and Dutch introduced their original architecture and many elements of European architecture to the region which was affected by the native traditions. Nevertheless, the adoption of concepts was not a simple procedure. The Dutch then implemented the local architectural features to generate a distinctive form of colonial architecture recognized as the Indies architecture. Dutch lately turned to the local tradition as a basis of creation for a new tropical architecture as a combination of the traditional principles with the modern building materials and its construction techniques.

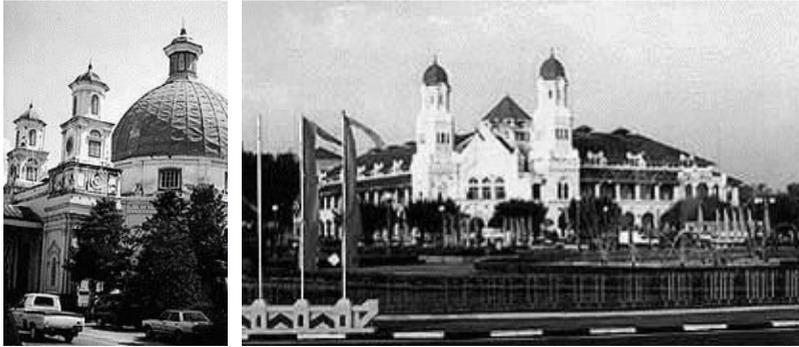


Fig. 5. Blenduk church and Lawang Sewu building, examples of the Dutch architecture [8]

The Dutch built the most colonial buildings in Indonesia in 1602 – 1945 with unique architecture, especially in the later occupation time. The architecture is the result of the cross-culture between the western and eastern in some aspects including in the building type and form related to their building acclimatization in the tropical region was done. The Dutch's colonial architecture in Indonesia is broadly acknowledged as different with their origin as found in their homeland, Netherlands [14]. They were produced from the combination of the colonial-modern techniques and the local and traditional principles of the many cultures in Indonesia (Fig.5). The correlation between building and people is mostly the difference between Western and Indonesian architecture where the Western's see the building as construction, while the Eastern think that a house is a personification of the user [14]. The primary consideration of Dutch buildings in Indonesia was the local climatic condition which is very different if compared to their home.

The Dutch did not suddenly discover the appropriate architecture to be applied in Indonesia. In the early their occupation in the 18th AD, they constructed the similar four seasons building as they used to with the thin facade without a veranda. Finally, they constructed the building with larger windows and more significant eaves accomplished with a lot of the ventilation holes such as they build in Batavia [15]. Many of these buildings were built in Java Island as their center of activities and in the same time used for the military purpose as for a fort [6]. In the establishment, they imported the materials directly from Holland such as the bricks and roof tiles, but later they developed their own materials industries in Java. The colonial architecture was also completed with big veranda mostly constructed in the front area just as found in Pendapa in Javanese building.

The colonial house synchronization was not only for tropical thermal purposes but also for the very active tectonic land of Indonesia. Though the Dutch constructed the building utterly different from the traditional houses, the lateral forces had come to mind to be considered especially when they lately build significant buildings.

2.3 Indonesian contemporary architecture and threat of earthquake

The modern development acquired a place in Indonesia right after the Independence in 1945 especially when the Indonesian economy was starting to grow in the period of 1970s to 1980s. The massive building programs were operated by the government starting from low-cost housing to industrial buildings, airports terminals, shopping centers, and high-rise buildings. Many of them, especially the prestigious ones, were designed by foreign architects who designed without or very least considering Indonesian context. Just like other parts in the world, the modern architecture in Asia in the '70s was increasingly growing without respecting the local histories, climate, and cultures. Postmodernism has encouraged a 'new architecture' versus the local architectural heritage.



Fig. 6. Contemporary Houses in Indonesia [16]

What known as the 'local Indonesian architecture' commonly ensued in the 50s with the ascendancy a form of the roof in any scale of any building including in a multistory building. The old-colonial building architecture was modernized with new equipment such as the use of concrete construction, air conditioning system, and also elevator device. Because the economic condition in Indonesia was not yet stable enough, the simpler and cheaper building was utilized to find the modern Indonesian architecture such as the use of the Joglo roof. According to the economy level of the owner, there are many styles arise in the residential sector as the contemporary house beside the vernacular (Fig.6). The modern houses are constructed with the concept of small space, lower budget, and judged with the rational construction [6].

Modernization in buildings, especially in housings, brings a new era of architecture in Indonesia. The new paradigm did not entirely replace the traditional styles but accommodating the new to the old. The adjustment in the way the houses being built was also affecting the way of thinking of the people. On the traditional architecture, the principles in building construction are guided by the tradition of both written and oral rules. By this way, the aims of the construction and its process are kept in the certain definite customs to manage the significant aspects are not missed. Unfortunately, these processes are not followed by the modern construction principles which are significantly different both in technique and social aspects.

The introduction of the brick wall in the Dutch colonial era and lately the Portland cement (PC) in the pre-independence era have changed the building traditions related to building safety in Indonesia. The light wooden structures were replaced or combined by the massive brick and PC in most of the contemporary houses [5]. The interpretation of prosperity was also correlated with the capability to own brick houses which are different from previous traditional dwellings. The people then massively build the houses without or less considering the technical aspects such as its ability to deal with the tropical nature and earthquake-prone area. The stiffness of the houses on a heavyweight structure is then the most critical factor which is, unfortunately, less considered since the limitation of economy, knowledge, and skill of the people. The decreasing resources in timber materials because of massive deforestation also triggered the change of direction in housing construction in Indonesia since the material price increased sharply. Many earthquake occurrences recently proved that the building failure was high because of the improper use of these new materials (Fig.7).



Fig. 7. Modern and vernacular building failures after an earthquake [17]

The Indonesian government has released some codes related to the building's safety under earthquake [18], [19]. These regulations are regularly updated according to the advance knowledge in building safety and some latest earthquake occurrences in Indonesia. However, this guidance only reaches the engineered building while the vernacular building is still barely touched. Furthermore, building safety comparisons under earthquake which suggest the use of more safety type of structural system is yet unavailable.

3 Conclusions

Indonesian architecture is proven to be related with every civilization era starting from the classical period, external influences from Islamic and western culture, and post-independence time. Each age the civilization is characterized by distinctive architecture that has the specific approach to deal with the people and nature. There are many options for the houses to synchronize the hazard-prone environment with accessible materials and techniques. However, some of the principles have been misused by neglecting the original rules or mixing between the techniques which were resulting in many failures affecting building safety.

Traditional Indonesian architecture is the form of tradition resulted from long-time adaptation to the nature and way of living of the people. Abundant resources from nature such as wood, bamboo, and rattan had been used for the houses thousand years before. The tradition is believed as the proper way to adapt nature since it was developed from a long journey of trials and errors. Many samples from traditional houses in Indonesia explain the proper way to deal with the earthquake. Unfortunately, the long history of disasters in Indonesia seems to be neglected in some ways especially by the development of modern houses. The introduction of new materials such as the massive wall and roof which were never utilized before have placed the people more comfortable to follow but hard to differentiate the appropriate technique. The continuation or development of modern house leaves the critical aspect of the older houses which were prepared for the environment, mainly from the earthquake. The limitation of economy and knowledge somehow decrease the quality of both traditional and modern houses resulting in the highly vulnerable houses in Indonesia.

For this reason, the consistency in building development based on the architectural style or building technique application is very critical to gain the building safety. Classic, vernacular, or modern building must be constructed with the specific pattern of a structural system. Light construction with light materials is the answer for the classic houses and vernacular dwellings while the integrated and rigid system is the way for modern architecture. There is no other way to articulate one with other; otherwise, the building safety will not be achieved.

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