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Seismic performance of South Nias traditional timber houses: A priority ranking based condition assessment

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Abstract. Due to incessant earthquakes, many historic South Nias traditional timber houses have been damaged while some still stand today. As Nias is part of an extremely active tectonic region and the buildings are getting older by day, it is essential that these unique houses are well maintained and functioning well. A post-earthquake condition assessment was conducted on 2 selected buildings; 'Building A' survived the seismic shakings while 'Building B' got severely damaged. The overall condition assessment of "Building A' was found out to be poor and the main structural members were not performing as intended. In 'Building B', the columns were not well anchored to the ground, no tie beams to tie the columns together, and eventually, the timber columns moved in various directions during the earthquake. The frequent earthquakes along with deterioration due to lack of proper maintenance program are responsible for the non-survival of the buildings. Thus, a process guideline for managing the maintenance of these buildings was proposed. This is necessary because managing the maintenance works could help to extend the life of the buildings and seek to avoid the need for potentially expensive and disruptive intervention works, which may damage the cultural significance of the buildings.

Keywords: building defects; condition assessment; defect intensity index; earthquake; seismic shaking; traditional wooden house

1. Introduction

The South-eastern part of Asia is home to renowned traditional wooden architecture that are considered as highly valuable assets due to their strong architectural and cultural significance and tourism potentials (Wiryomartono 2020, Asfarilla and Prihatmaji 2019). Notable among these historic timber houses are Indonesia's South Nias traditional timber houses (Ulfa 2015). Nias, which is an island located off the western coast of Sumatra, Indonesia, is part of an extremely active tectonic region (Nitto *et al*. 2016). Due to its precarious position on the fracture zone of the Indo-Australian and Eurasian tectonic plates, Nias is frequently shaken by seismic events (Nitto *et al*. 2014; Uekita *et al*. 2013). Ironically, this prompted the natives to fondly tag Nias as the "dancing island". Although there is no volcanism, the island of Nias has very unstable ground condition with huge regional disparities.

The composition of building stock in Nias Island is such that most of the buildings are predominantly non-engineered, largely made of confined masonry half-burnt brick, concrete block, and timber while the other few are engineered buildings involving mostly reinforced concrete combined with masonry walls (Sadaka *et al*. 2013; Boen 2006, Nzara and Resosudarmo 2007). Nonetheless, like in many other places across South Asia, the damages to the buildings due to earth shaking, cut across the engineered and non-engineered building divide as both engineered and non-engineered structures got seriously affected by the impact of the earthquake (Gautam *et al*. 2016, Prihatmaji *et al*. 2014). A large number of engineered buildings got damaged while some non-engineered buildings, which are mostly historic timber buildings with high cultural significance, survived the earthquake (Awaludin *et al*. 2010).

Although some of these historic timber buildings got destroyed, early post-earthquake assessments seem to suggest that the major cause of the destruction was attributed largely to deterioration due to lack of proper maintenance program for preserving the buildings. Most importantly, the indigenous people and communities of this region regard these historic timber buildings as the fundamental cultural heritage elements that strengthens their identity and sovereignty, which they cherish to preserve and pass on to future generations (Hanazato *et al*. 2014). As these historic wooden buildings are getting older over time and being shaken persistently by seismic activities, it is paramount to ensure that they are kept safe, in good condition and functioning well (Lyu *et al*. 2016).

In view of these, it is essential to conduct condition assessments on the buildings that got damaged during the earthquake and those that survived (Pardalopoulos and Pantazopoulou 2016). For the building that survived, this study will seek to assess the buildings' level of maintenance condition to ascertain if intervention works like repair or replacement is needed. A comprehensive assessment is necessary when determining the condition of a historic

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timber house in order to provide effective and prompt recommendations. Thus, the prioritized ranking method established in this paper is suitable for this objective. To further simplify the condition assessment process, numerical coding is used for the survey proforma and the data generated is used to ascertain the condition of the building as very poor; poor; fair; good; and very good. One of the most salient aspects of building condition assessment is to examine the defects associated with the building, where the deterioration state of the building will be investigated, and the extent of required intervention works will be determined (Che-Ani *et al*. 2008). Thus, before initiating any intervention works like repair or restoration, it is necessary to understand the cause of the defects, which could help to lower the risk of greater damage.

This paper aims at providing a methodical approach for assessing defects associated with historic wooden houses that have high cultural significance. Although quite a number of studies have been published focusing specifically on rating the condition of historic buildings generally, not many studies have been tailored towards traditional timber houses that were made from unique wood and techniques. Nonetheless, significant effort was made by Che-Ani *et al*. (2009). The authors established some visual condition evaluation criteria, which actually inspired this research. However, a notable limitation to their established ranking system is that it does not indicate the prioritized maintenance actions for each category of building condition assessment.

For instance, if the final score of a particular building falls between 1 to 5 on the rating scale, it then means, the building condition is considered "very good". This strongly indicates that the building condition is as good as new and major structural elements are fully functional as intended. It goes further to suggest that there are no visible defects on any of the building elements and all building elements are well maintained. Thus, 'proactive maintenance' is what the building would require once its calculated score for its physical condition assessment falls in the range of 1 to 5. The inclusion of the type of maintenance action required, which is established in this study, enhances the previous criteria developed Che-ani *et al*. (2009) for assessing building condition and determining the severity of defects observed on historic timber houses. Similarly, various authors (Yacob *et al*. 2016, He *et al*. 2015, Johar *et al*. 2013, Che-Ani *et al*. 2009, Hoxley 2002, Alani 2001, Hollis and Gibson 2005, Pitt 1997) have established criteria for assessing physical condition timber buildings. However, assessing building condition of historic timber houses that have been gazetted as heritage buildings requires special criteria that takes into consideration the cultural significance and nostalgia attached to such buildings. Thus, such buildings need specialized care and intervention works.

The paper will further seek to introduce a fundamental process guideline to Nias Heritage Foundation and Tourism and Culture Office of South Nias on how to manage the maintenance & repair works on their historic timber buildings. This is considered crucial because effective management of maintenance & repair works are vital in extending the life of historic wooden houses (Lyu *et al*. 2016, Pardalopoulos and Pantazopoulou 2016, Karantoni 2013). Thus, this would help to avoid the need for potentially expensive and disruptive repair works, which may damage the cultural significance and values of the buildings (Fahmy and Wu 2018).

Fig. 1 South Nias typical residential timber house

2. An overview of South Nias traditional timber houses

The Nias traditional houses are famous for their unique steeply pitched roofs and skylights, constructed without the use of single nail. The ground floors are elevated about 2-3 meters above natural ground level. As shown in Fig. 1, the houses are mainly made of wood, constructed on wooden columns, and have outward-leaning wooden walls and huge two-sided roof (Wiryomartono 2020). The roof structure, which has no inner ceiling is supported by an intricate system of vertical and diagonal members. It has moveable panels that can be easily opened for ventilation. A typical Nias traditional house does not have heavy roof materials but has diagonal bracing made from strong timber placed at the bottom, over the ground as well as under the floor. The much-needed support for roof structure comes from the four major columns that are laterally underpinned by diaphragm action of the timber floor, which comprises of wooden beams in grid system with thick timber board (Lyu *et al*. 2016).

The distinctive and intricate wooden architecture of Nias is so unique that it is hard to find in other parts of the world especially the blend of functional and creative architectural features coupled with most effective use of space (Viaro 2008). The houses are all partitioned into a public space, which is always located at the front and an inner private space, usually right behind the public space. The indigenous people of South Nias were predominantly warriors and their houses are some sort of a defensive habitat, which were well fortified. The design of the houses and the general layout of the villages in Nias underline the significance attached to defence. The wooden columns are usually 2-3 m high. A portable wooden ladder is used to reach the main

Fig. 2 Interior of the front public room of a South Nias timber house

entrance, which is a strong wooden door that is securely closed at night and when there is an imminent danger. The front public room shown in Fig. 2 has a fortified door that separates it from the private areas of the house (Viaro 2008).

2.1 Use of materials

Remarkably, the houses are constructed without the use of single nail or screw, instead the various components are jointed and pegged. Ebony wood, a dense black/brown hardwood is mostly used for the construction (Ramage *et al*. 2017), bamboo is used for the roofs, sago palm leaves used for roof thatching while coconut fibres are used for binding. The roof thatching is mainly made of pre-arranged panels attached to the structure. For the roof structure to withstand strong winds, the roof ridges are reinforced by using crossed poles of bamboo wood, which is securely bound to the roofing material (Xue *et al*. 2018b). While steep angle of the roof prevents the roof panels from being blown up by windstorm, the rafters and the battening to which the roofing panels are tied provide cohesion of the entire roof structure (Viaro 2008).

2.2 Performance under seismic loading

Remarkably, the houses could resist strong earthquakes much better than present-day houses. This is not surprising as the Nias Island is prone to frequent seismic activity, thus, the natives found a distinctive way to make their dwellings safe from earthquakes. In order to reduce the impact of the incessant tremors on the traditional wooden houses in the area, the natives developed a technique that is quite distinctive in the world of vernacular architecture. The houses are not anchored into the ground directly, rather, they are set on a series of vertical timber posts and bracing posts, thereby erecting a very sturdy 3D structure that allows necessary flexibility during seismic shakings (Rossi *et al*. 2020). Since the structure (house) is not anchored to the ground, timber logs or rocks are usually placed as ballast on the diagonal pillar under the house to weight it down, which helps to prevent the house from moving during earthquakes or storms (Gu 2016). The bracing posts are usually inclined and lean against each other at the base while at the top, they fit into the horizontal beams laid beneath the floor of the house. In essence, the bracing posts are used along the building and across it. Similarly, this arrangement is applicable to the roof structure although just the transverse slanting purlins, crossing in their centre, lean at their top and bottom ends on the vertical and horizontal sections of the structure. Thus, when the ground shakes, the bracing components of the substructure and superstructure will support the structure and ensure that the entire structure remains stable (Xue *et al*. 2018).

On the other hand, the Nias traditional houses predominantly used the mortise and teon system for interlocking the beam-column joints or beam-beam joints. This system does not require the use of steel or metal fastener but mortise or tenon members that are used for mainly interlocking functions (Tsai and Wonodihardjo 2018). Thus, these houses are renowned for their survival after many earthquakes in Nias Island in Indonesia. This is largely attributed to the effectiveness of the mortise-tenon system of their connections along with the large cross-section of timber members, which gives powerful interconnectivity amongst the joint members with extreme frictional resistance or damping.

In other words, the effective mortise and tenon joint system provides better lateral integrity to structural elements in the wooden houses to resist the lateral forces of earthquakes. The strong frictional resistance formed among the mortise-tenon joint members absorbs almost all the earthquake energy. This function is akin to dynamic performance of log-construction, where the entire log layers react consistently as a huge body under a specific ground acceleration. For Nias traditional timber houses to survive damages from future earthquakes, it is essential to insert wooden dowels which would seek to ensure that the frictional action between two timber layers is effectively established. This is necessary because after the occurrence of some earthquakes, there is likelihood to have gaps or openings between the mortise-tenon joint members. Above all, for any repair or intervention works to Nias traditional timber houses, the concept of frictional damping should be fully implemented as it will serve as an efficient energy dissipating system.

3. Study area and methods

The Bawogosali village in Teluk Dalam, Southern Nias was the case study area for this paper. The entire village was built by the traditional timber construction method; it has very high historical, architectural, and cultural values and was registered on the World Heritage tentative list in 2009 (Nitto *et al*. 2016). Similarly, the village of Bawogosali is listed by the Tourism and Culture Office of South Nias as one of the twelve cultural heritage villages in Teluk Dalam. It is because the village has relatively superior traditional character and megalithic and wooden structures that are of high cultural significance to the people of the Island. The Bawogosali village consist of four smaller villages called '*dusun*' which are grouped together. These small villages are located on a hill below the Gomo

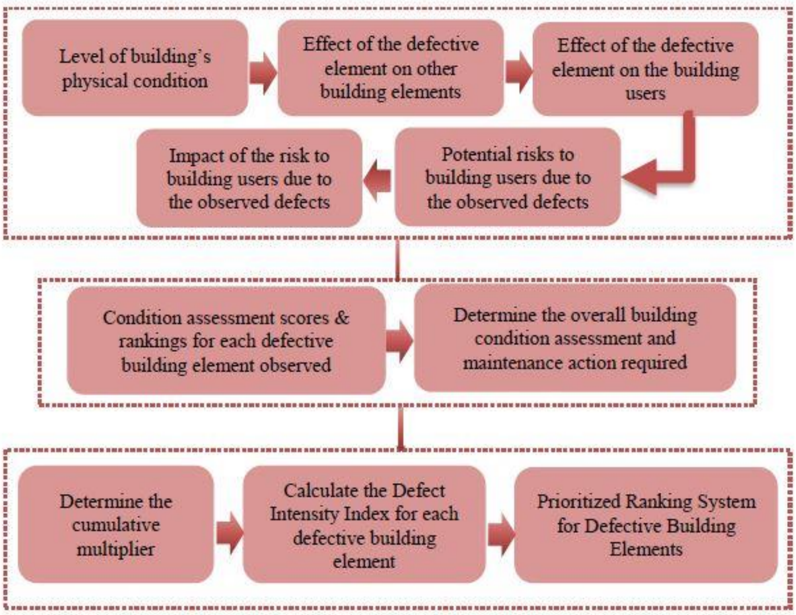

Fig. 3 Graphical presentation of the criteria for the prioritized ranking system of the defects

river, with over three hundred families living mostly in the traditional timber houses (Omo Hada).

Despite the incessant earthquakes bedevilling Northern Sumatra, many non-engineered historic timber buildings have shown satisfactory performance against the seismic loading. Two separate timber buildings ('Building A' & 'Building B') that now form part of the main building of a local museum in Bawogosali village were selected for this case study. The rationale for this selection is that during the most recent earthquake, 'Building A' survived the seismic devastations while 'Building B' got damaged completely. The selected wooden buildings were previously used by the community leaders as residences also serve as tourist attractions for tourists visiting the village before the most recent earthquake in the area.

3.1 Methods

Visual condition assessment was conducted on the building. The condition survey for the building was conducted using visual inspection methods. As pointed out by Che-Ani *et al*. (2009), the visual inspection carried out by an experienced surveyor is widely considered adequate in detecting the building defects as well as their respective causes. The visual inspection was smoothly conducted in clear weather from the ground level up to the roof beam and then the roof structure. As recommended by Hoxley (2002), prior to the commencement of the detailed examination, it is essential to conduct an initial assessment by simply going around externally and internally. The condition survey usually begins from the exterior using the proforma survey checklist, which is very crucial for preparing an accurate and comprehensive report (He *et al*. 2015, Ni *et al*. 2015). A major aspect of managing the intervention works for historic timber houses is the recognition, classification and assessment of the defects associated with the building. Most defects associated with historic timber houses usually occur through normal wear and tear (Johar *et al*. 2013). Though it is inevitable for old timber houses to have defects, the defects could still be well-managed. To start with, the visual condition survey is employed as a technique to assess the condition of the building and the outcome of the assessments is a report that highlights the problems affecting the building elements and is eventually used for budgeting and planning functions.

3.2 Condition assessment rating descriptions

This section provides descriptions of conditions corresponding to each condition rating for each building element. In order to ensure that condition assessments are conducted in a consistent and measurable way, standardised relative ratings have been developed for assessing the physical condition of timber buildings. A condition assessment rating or relative rating refers to the differential measurement between the condition rating. For instance, the required condition of a building, and the actual condition of the building as determined by the person undertaking the condition assessment. Tables 2 and 3 provide the condition assessment ratings and the definition for each rating, which are then used as a guide to assign a score to each element as they are evaluated. Accordingly, Table 4 provides the condition assessment scores & ranking for each defective building element observed. In order to properly explain the criteria in a more concise manner, Figure 3 provides a graphical presentation of the criteria for the prioritized ranking system of the defects. The figure shows the stages and sequence of activities to be undertaken to achieve the goal of the condition assessment. The criteria were presented in tabular forms using scale values, chronology values and linguistic values for describing the rating scale/criteria, which is supported by prominent researchers (Yacob *et al*. 2016, He *et al*. 2015, Johar *et al*. 2013, Che Ani *et al*. 2009, Hoxley 2002, Alani 2001, Hollis and

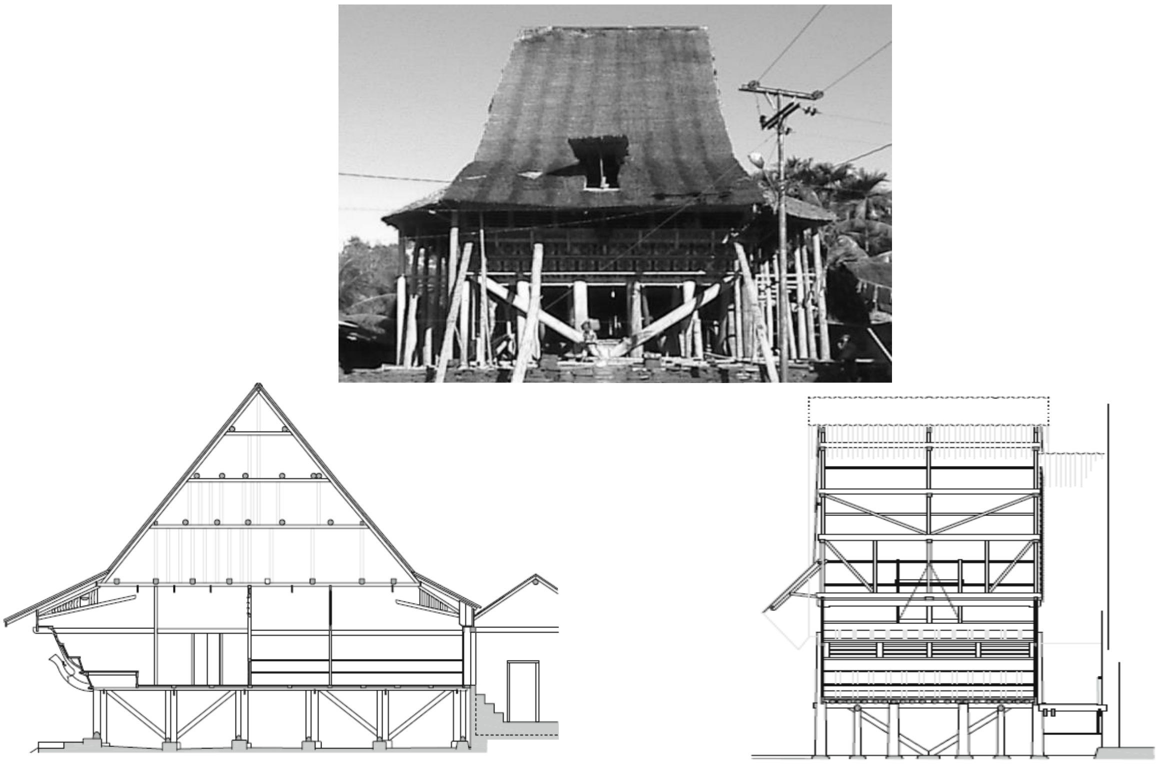

Fig. 4 Details of non-damaged "Building A" (a) three-dimensional view (b) cross section along the length (c) cross section along the width

Table 1 Details of Building A

No.	Category	Description
1	Category of building	Residential
2	Type of architecture	Vernacular
3	Type of building system	post and beam
4	Type of connection	mortise-tenon system
5	Type of timber	Ebony & bamboo
6	Floor area	540m²
7	Height of building	12.5 m
8	Age of building	92 years
9	Last major repair works	20 years ago

Gibson 2005, Pitt 1997) in assessing the physical condition of timber buildings.

4. Results and discussion

4.1 Condition assessment of non-damaged Nias traditional timber houses

Building A had for long been used as a private residence before its conversion to a tourist site (Fig. 4). Many parts of Building A remain the same since it was constructed, which makes it highly treasured cultural heritage. Some of the building's details are provided in Table 1. The substructure of Building A comprises of sixty-two short pillars and forty cross pillars. The short pillars are 4m long and the diameter is about 48 cm, while the cross pillars are about 7m long, having a diameter of about 45 cm. The superstructure of the building is used for daily life. The front room is quite spacious with no pillars and has an approximate area of 140 m². This room serves guests and visitors, and the villagers can also enter it freely. The 25 m² backroom is reserved for the head of the family and has a wooden staircase attached to it.

The roof of the building is supported by the wooden columns and walls, and about 20 crossbeams are bridged across the tie beam keeping a meter interval with struts erected on them. The tie beam is 60 cm long and 9 cm wide and while the collar beam is 45 cm in diameter. The struts are alternately set up at an interval of 25 cm and they are of 2 types; the first type is 10 cm wide and 5 cm thick and the second type is 5 cm thick and 25 cm wide. These struts are alternately set up at an interval of 25 cm.

The visual survey was conducted through observation of the surrounding area, checking out the observed defects, and prediction of suspected causes. This is followed by suggesting the degree of urgency required to rectify each of the defects in order to preserve the fabric of the building and prolong its basic functions. The broader objectives of the visual condition survey are to determine the defect intensity index of each of the defects. Based on the intensity of the defects damage to the building fabric and users, the building elements need to be fixed.

By using the prioritized ranking system, the visual investigation is then used to assess the condition of the buildings which could be very good, good, moderate, poor, or very poor. To prioritize the defects observed and assess the physical condition of each heritage building; the defects, the affected building elements and causes of defects were noted and recorded.

Table 2. Data for physical condition & risks for ranking of building defects

Rating Criteria		Rating Scale		
Code	Category	Score	Description	Interpretation
PHY-D1	Level of the building's physical condition	1	Repair works not required	No defects detected on the building element
		2	Repair works required within 24 months	Minor defects detected but the building element remains structurally sound
		3	Repair works required within 12 months	Some major defects detected but the building element remains functionally sound
		4	Repair works required within 6 months	Severe defects detected and building element may not function satisfactorily
		5	Repair works required within 1 month	Building element is completely not functional
PHY-D2	Effect on the building fabric	1	Insignificant	If a specific building element becomes defective, what will be the likely effect on other building elements or structures?
		2	Minor	
		3	Moderate	
		4	Significant	
		5	Major	
PHY-D3	Effect on the building users	1	Insignificant	If a specific building element becomes defective, what will be the likely effect on end-users of the building?
		2	Minor	
		3	Moderate	
		4	Significant	
		5	Major	
RSK-D1	Potential risk	1	Rare	The risks that could cause injury or fatality to users due to structural damages to the building
		2	Unlikely	
		3	Possible	
		4	Likely	
		5	Almost certain	
RSK-D2	Risk impact	1	No apparent injury	
		2	Possible Injury	
		3	Minor injury	
		4	Serious Injury	
		5	Fatal Injury (death)	

Note: PHY-D: Physical condition data; RSK-D: Risk data

Table 3(a) Matrix analysis

Scale			Prioritized Maintenance Actions (PMA)				
			PMA5	PMA4	PMA3	PMA2	PMA1
			5	4	3	2	1
Physical Condition of Building	*Very Good*	*5*	25	20	15	10	5
	Good	*4*	20	16	12	8	4
	Moderate	*3*	15	12	9	6	3
	Poor	*2*	10	8	6	4	2
	Very Poor	*1*	5	4	3	2	1

Furthermore, the physical data and the risk data were obtained. The physical data is more concerned with the building condition at the time of the visual survey while the risk data deals with the potential danger that might occur to the building especially the risk of structural damages, which in turn could cause health and safety problems to the occupants. The physical data was further divided into three categories namely "level of the building's physical condition", "effect on the building fabric" and "effect on the building users". The risk data on the other hand was divided into two categories namely "potential risk" and "risk impact". The scale, chronology and linguistic values for physical and risk data are provided in Table 2.

The scores of the physical data and risk data were summed up to obtain the prioritized ranking of the defects. The total score is 25, which indicates that the higher the total score, the higher the priority that should be given to the defect and the building element on which it occurred. Next, the general condition assessment of the building was deliberated to find out whether the building was very good,

Table 3(b) Rating of building condition assessment & maintenance action required

Condition Ranking	Score	Physical Condition of Building	Description	Prioritized Maintenance Action (PMA)
A	1 to 5	Very Good	The building condition is as good as new, major structural elements fully functional as intended. There are no visible defects on any of the building elements, all building elements are well maintained.	PMA1: Proactive Maintenance
B	6 to 10	Good	Visible minor defects but the structural members of the building are performing as predetermined. There is a need for close monitoring & control to avoid serious damages.	PMA2: Condition-based maintenance
C	11 to 15	Moderate	The building condition is fair but with serious defects; the main structural members could still function under an effective maintenance program. Major intervention works become essential.	PMA3: Repairs
D	16 to 20	Poor	Serious defects that are critical to building stability are observed clearly on structural elements of the building; the main structural members not performing as intended. Very urgent repair works are required.	PMA4: Rehabilitation
E	21 to 25	Very Poor	The building condition is structurally not safe for occupancy as major elements of the building have failed. Very urgent replacement works are required. Expert judgement should be sought before taking decision on any intended intervention works.	PMA5: Restoration

Table 4 Condition assessment scores & ranking for each defective building element observed

Building Element	Defects	Visual inspection scores and rankings for observed defective elements						
		PHY-D1	PHY-D2	PHY-D3	R-D1	R-D2	Total Score	Ranking
Beam	Inclination	5	4	5	5	5	24	2
	Dampness	3	5	2	2	2	14	8
	Termite Attack	5	5	4	4	4	22	4
Column	Dampness	3	5	2	2	2	14	7
	Inclination	5	4	5	5	5	24	2
	Termite Attack	5	5	5	4	4	23	3
Floor	Dampness	5	5	4	3	3	20	6
Roof	Leakage	5	5	5	5	5	25	1
Wall	Dampness	3	5	2	1	1	12	9
	Termite Attack	4	5	4	4	4	21	5
Average Score							19.90	
Condition E (16-20): Poor - Rehabilitation Required								

good, moderate, poor, or very poor. The assessment was done based on the linguistic values and average marks of the five conditions provided in Tables 3(a) and 3(b).

The overall condition assessment of the building is ‘Poor’. From Table 4, it could be seen that the average score for the prioritized defective elements is 19.90, which falls within the range of Condition Ranking D (16 - 20) which was assigned for ‘poor’ building condition in Table 3b. In essence, the main structural members are not performing as intended and very urgent intervention works are required.

The visual condition survey of the building elements was carried out to reveal any associated defects that may affect the safety, functionality, and cultural significance of the building. Leakage in the roof was first spotted, and this probably allowed penetration of rainwater droplets into the building, which caused rise in dampness and moisture on beams, columns, and floorboard. Ultimately, this led to gradual deterioration of the timber (manawa dano) and damage of these structural elements. The deteriorations caused by dampness due to humidity is observed in both cross and short pillars in Fig. 5. About 25 short pillars and 10 cross pillars are due for replacement. Similarly, termite attacks have caused serious defects to the columns, beams, and walls as shown in Fig. 6. On the other hand, most of the parts of these elements have decayed due to the termite attack. The defects caused to the roof as seen in Fig. 7 were caused by the rain penetration through the wide gable.

The level of intensity for each building defect is determined by calculating the defect intensity index. To do so, the frequency (number of occurrences of the defect) and risk effect score for each defect is obtained. The frequency is then converted into percentages and the risk effect score is matched with cross reference table (Table 5) to get the cumulative multiplier.

The cumulative multiplier is then used as weightages for risk effect score, with 0.20 assigned for each risk effect score. The defect intensity index is then calculated using the

Fig. 5 Dampness on columns and floorboards

(a) (b)

Fig. 6 Termite attack (a) columns and beams, (b) walls

(a) (b)

Fig. 7 (a) Leaking roof, (b) Roof frame deterioration due to rain penetration

Table 5 Cross-reference table for determining the cumulative multiplier

Nature of the Risk Impact	Risk Impact Score	Multiplier	Cumulative Multiplier
No apparent injury	1	0.20	0.20
Possible Injury	2	0.20	0.40
Minor injury	3	0.20	0.60
Serious Injury	4	0.20	0.80
Fatal Injury (death)	5	0.20	1.00

formula below. In interpreting the intensity of the defect, the highest percentage signifies the most severe or serious defect.

Defect Intensity Index = Frequency (%) x Cumulative Multiplier of Risk Effect

At the end of the visual survey, the prominent defect observed on elements of the building occurred on the roof structure of the building. As shown in Table 4, the most notable defect is leakage, which resulted to dampness and moisture penetration on other structural elements like beams, columns, walls and floors. The roof was observed to be leaking causing rainwater to penetrate the building. The

Table 6 Defect intensity index

Types of defects	Frequency	Frequency (%)	Aggregated Risk Effect Score	Accumulate Multiplier	Defect Intensity Index	Defect Intensity Index (%)
Termite attack on beams, columns & walls	5	8.33	4	0.80	6.67	6.97
Dampness on beams, columns, floors & walls	4	6.67	3	0.60	4.00	4.18
Inclined columns & beams	16	26.67	5	1.00	26.67	27.87
Roof frame deterioration due to leakage	35	58.33	5	1.00	58.33	60.98
Total	60	100.00			95.67	100.00

leakage was due to old age of the roof and the actions of excessive rainfall and warm sunshine in the area where the building is located. The roof defect is considered serious as the roof cannot function to an acceptable standard. Thus, it needs repair within the period of six months. Despite having a very significant effect on the fabric of the building and the building users; the roof has very high potential risk for structural failure which in turn can lead to death or serious injuries.

The intensity index of the leaking roof in Table 6 shows that the defect has the highest severity index (60.98%). This confirms and justifies the ranking of the roof element as the most serious defective element requiring top priority. The next most intense/severe defect is inclination of column and beams. The columns and beams were observed to be inclining which is quite dangerous to the building users, and the building itself. The probable causes for the inclination could be dislocation of the frame joints during seismic shaking, distortion of the structural members due to prolonged exposure to extreme tropical weather, or a combination of both.

Not that alone, beams and columns that have inclined are not only unsightly; they can eventually fall and become very dangerous. Despite having a very significant effect on the fabric of the building and the building users; the inclination has very high potential risk for structural failure which in turn can lead to death or serious injuries. However, in the analysis of severity index shown in Table 4, the inclination of beams and columns is not as critical as the leaking roof. The inclination of beams and columns got a defect intensity index of 27.87%, which indicates that the defect is equally serious and requires quick intervention within the period of one to six months.

4.2 Condition assessment of damaged Nias traditional timber houses

The details of Building B are presented in Table 7. Since the building got severely damaged and collapsed due to seismic shaking (Fig. 8), the main focus of the assessment was to determine its vulnerability and provide strategy for strengthening, maintaining and repairing other valuable Nias traditional timber houses that have survived the previous earthquakes. Solarino *et al*. (2017) and Nitto *et al*. (2016) used visual inspection methods to observe and identify the damages suffered by the structural elements of 'Building B'.

Nonetheless, the damaged 'Building B' was investigated from its damage condition in relation to its structural vulnerability. Nitto *et al*. (2016) classified the damages into 2 main categories: 'connection between column & stone base' and 'column & beam connections'. These connections are shown in Fig. 9. As for the 'connection between column & stone base', the tenon at the end point of the column is supposed to secure the position of the columns on the foundation thereby making the structural system strong enough to withstand seismic lateral forces even when the columns are inclined. Solarino *et al*. (2017) observed that some columns did not have the original tenons, thus, the severe damage of the joint between the foundation and column became inevitable. Consequently, columns simply slipped over the stone-base foundation causing serious damages to the structure. Failure of the joint between the foundation and column represents a significant factor with regards to stabilization of a structure after a seismic activity.

Fig. 8 Damaged Building B (Source: Solarino *et al*. 2017, Nitto *et al*. 2016)

Whereas in the 'connection between columns & beams', the mortise and tenon joints of the building provide rotational resistance to lateral forces. The most severe damage was observed at the joint of the column and long

(a) (b)

Fig. 9 Connection details (a) between column & stone base, (b) between column & beam

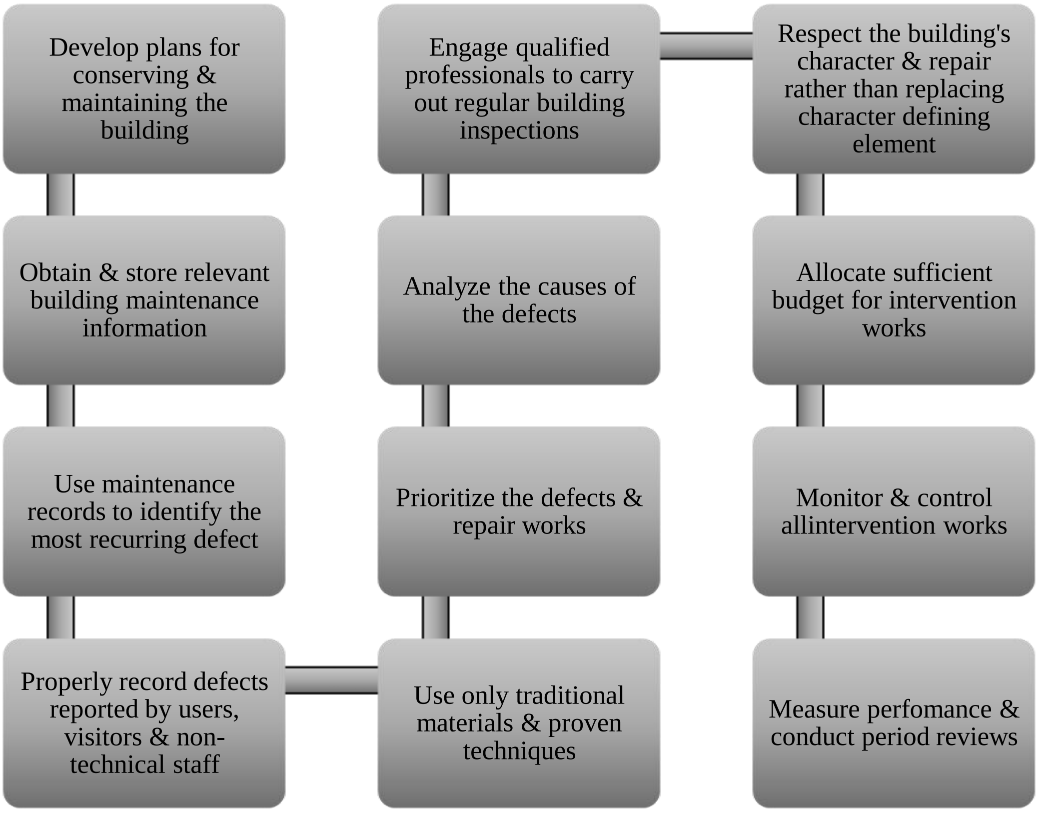

Fig. 10 Guideline for efficient management of intervention works to historic timber buildings

beam, which was due to bending moment as well as shear force inside the mortise. It was also apparent that the severe damage to the building might have occurred due to the number of beams that were inserted into mortise of columns.

4.3 Summary

Most of the defects spotted in the visual investigation of 'Building A' have been neglected to reach the stage they have reached now due to poor maintenance of the buildings. Further discussions with custodians of the building revealed that intervention works like maintenance, repair and renovations are merely carried out on ad-hoc basis by the Nias Heritage Foundation with no competent maintenance workforce and no comprehensive plan for managing the conservation of the building. Findings of this case study have indicated that the poor maintenance and other related intervention works on the building contributed largely to the poor physical condition of the building.

While it is clear from the visual inspection that 'Building B' got damaged during the seismic shaking. Findings of the post-earthquake assessments showed that the major cause of the destruction was attributed to deterioration due to lack of proper care and maintenance program for preserving the buildings. Broken mortise of columns, decline of columns, broken joints between outer ring's beams & columns, broken joints between inner ring beam and rafters, columns were not well anchored to the ground, no tie beams to tie the columns together, and eventually, the timber columns moved in various directions during the earthquake.

Thus, this paper proposes a process guideline (Figure 10) to provide some guide on how to efficiently manage the intervention works to historic timber buildings. Efficient management practices for the intervention works are essential in extending the life of historic wooden houses and avoiding the need for potentially expensive and disruptive intervention works, which may damage the cultural significance and values of the structure.

5. Conclusions

The Nias traditional timber house (Omo Hada) have high cultural significance to the people of Indonesia. In spite of the persistent seismic events in Northern Sumatra, many of these wooden historic houses are still standing today due to their traditional structural system. While many of these wooden houses survived the incessant earthquakes in the region, some few got damaged not mainly due to the seismic events in the area but deterioration that was attributed to lack of proper maintenance. Two separate buildings that form part of the main building of a local museum in Bawogosali village in Teluk Dalam, Southern Nias were selected for the case study. ‘Building A’ survived the most recent seismic devastations while ‘Building B’ got damaged.

Since ‘Building A’ survived the earthquake, thus, a condition survey was carried out to develop a defect priority ranking approach for the building. The approach provided an evaluation of the entire building condition in relation to stability of the building and ascertaining the intensity index for each type of defect observed on the building. The condition survey for ‘Building A’ indicates that the building’s overall condition is poor. In essence, serious defects that are critical to the building’s stability are observed clearly on the main structural elements of the building (e.g., roof, columns & beams) and these main structural members may not be performing as intended. Thus, at present, urgent rehabilitation becomes the prioritized maintenance action recommended for the building. ‘Building B’ on the other hand got damaged during the seismic shaking. Findings of the condition survey suggest that the main cause of the destruction was attributed to deterioration due to lack of proper care and maintenance program for preserving the buildings. The columns were not well anchored to the ground, no tie beams to tie the columns together, and eventually, the timber columns moved in various directions during the earthquake.

The paper further proposed a process guideline to *Nias Heritage Foundation* and *Tourism and Culture Office of South Nias* on how to manage the intervention works on historic timber buildings. This development of the proposed framework is considered essential because effective management practices for the intervention works are vital in extending the life of historic wooden houses. This would help to avoid the need for potentially expensive and disruptive intervention works, which may damage the cultural significance and values of the buildings. As most of the Nias traditional timber houses were constructed at a time when codes and standards for construction were not available in Indonesia. It is recommended that future works could focus more on establishing acceptable codes and standards for historic traditional timber houses, particularly in the aspect of identifying and categorizing seismic-damaged wooden structures.

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