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SANTEN-fuse AS ANEARTHQUAKE DAMPER FOR *PENDOPO JOGLO*

MAER, Bisatya W.[1*], PUDJISURYADI, Pamuda[2]
[1] Department of Architecture, Faculty of Civil Engineering and Planning, Petra Christian University,
Jl. Siwalankerto 121-131, Surabaya 60236, INDONESIA
[2]Department of Civil Engineering, Faculty of Civil Engineering and Planning, Petra Christian University
Jl. Siwalankerto 121-131, Surabaya 60236, INDONESIA
*Corresponding author: mbm@petra.ac.id

ABSTRACT

The 2006 Yogyakarta earthquake resulted in collapse of several traditional buildings in Yogyakarta, including *joglos*. This fact indicates that *joglos* are quite vulnerable to low-frequency ground shaking. The stability and rigidity of a *joglo* building are provided by the core of the building, i.e. the *rong-rongan* structure, in which connection of *sakaguru* (*the column*)-*sunduk* (*the long span beam*)-*kili* (*the short span beam*) has a rigid characteristic. This rigid *rong-rongan* structure behaves elastically during an earthquake event, and attracts large inertia force. This research aims to increase the structure performance of the *rong-rongan* by adding "SANTEN-fuse," an earthquake vibration damper, and by changing the joint connection of *sakaguru-sunduk-kili* to be that of a pin connection, but not changing the physical appearance of *rong-rongan*. *Santen*, whose function is to transfer the load of the roof from blandar to *sunduk* and from pangeret to *kili*, is modified so that it has frictional damper characteristic. This "SANTEN-fuse" can resist shear force up to certain level before it slides and acting as a damper. With the reduced stiffness, which leads to reduced inertia force, the overall structural responses are expected to be lower. An experimental quantitative method was used by doing a simulation using SAP2000 software to verify the idea. The *pendopo dalem Yudonegaran* a *joglo* house in Yogyakarta was chosen as a case study. Non-linear time history analysis was conducted. Simulation results showed that the proposed modification of rong-rongan structure by using "SANTEN-fuse", performed better than the original *rong-rongan* structure.

Keywords: *Rong-rongan*; SANTEN-fuse; non-linear time history analysis; structural responses.

INTRODUCTION

Pendopo joglo is one of the most valuable traditional architectural masterpieces in Indonesia that needs to be conserved. *Pendopo* is an important part of a traditional Javanese home, and is located at the front part of the house. The *pendopo* functions as a space to socialize with family members, relatives, and even neighbors, actualizing a form of harmony between the house inhabitants and the local community (Hidayatun, 1999), while *joglo* refers to a particular type of a traditional Javanese building.

The 2006 Yogyakarta earthquake resulted in the damage, even the destruction of some *pendopo joglos*. The *pendopo joglo* building consists of three parts (Figure 1a), i.e. the *guru* sector that is located in the centre of the plan, the *pananggap* sector that is located around the *guru* sector, and the *emper*/ *paningrat* that is at theedge of *pendopo* surrounding the *pananggap*sector (Prijotomo, 2005). Figures 1a shows a *pendopo joglo* plan, while Figure 1b shows the section of *sakaguru*, Figure 1c illustrates the three dimensional model of the building. In the *guru* sector, there is an element called *rong-rongan*, which is made up of four *sakagurus*, two pair of *blandars*, a pair of *pangerets*, a pair of *sunduks*, pair of *kilis*, and *santens*. On top of the *rong-rongan* is the *tumpangsari*, which consists of a stack of beams arranged in a formation that gradually widens to the top, and above the *tumpangsari* is *usuk-usuk pandedel* (Figure 1c, 2a). At the topmost part of *rong-rongan* there is *blandar* on the long side (c) and *pangeret* on the short side (f), see Figure 2b. Under *blandar* there is *sunduk* (b) and underneath pangeret there is *kili* (g). Between *blandar* and *sunduk*, also between *pangeret* and *kili*, at some *rong-rongan* there is *santen* (d). Prijotomo (2005) argued that *santen's* function is as a supplement, not in every *rong-rongan* there is *santen*. On *rong-rongan* with wide length, *santen* is placed to forward the roof weight and *tumpangsari* from *blandar* to *sunduk*/*kili*.The system of *rong-rongan* structure can perform as Moment Resistant Frame (MRF) because its stability and rigidity are formed by locking joint between *sunduk-sakaguru* (b dan a) and *kili-sakaguru* (g dan a), while the joint between *saka-blandar-pangeret* is a *pen* and hole connection thus has pin joint characteristic (Figure 3). The Diagram of Momen in Figure 4 (Ronald, 1987) assured that the connection between *saka-blandar-pangeret* (a-c-f) has pin joint characteristic.

In a research titled "*Perilaku rumah tradisional Jawa joglo terhadap gempa"* ("The performance of Javanese joglo buildings toward earthquake"), Prihatmaji (2007) proposed that *joglo* buildings were not stable in a low-frequency earthquakes, except when the support of *sakaguru* was changed into fixed support connection. The core structure that ensures the stability and rigidity of *pendopo joglo* is the *rong-rongan*, which is located exactly in the centre of the building plan. The structure of *rong-rongan* can perform as the MRF with a pin support connection because the joint connection between *saka-sunduk* and *saka-kili* is a rigid joint. Inside of a few *rong-rongan* structures, there is an additional component, which is *santen,* whose function is to transfer the load of the roof from blandar to *sunduk* and from pangeret to *kili*.

In this research, the structural concept of the MRF is changed by modifying *santen*'s function to be the only lateral shear force support component as well as an earthquake vibration damper. The joints between *saka-sunduk* and *saka-kili* are changed to be pin joint connection, while the support of *sakaguru* remains pin support connection. This new model of *santen* with an altered function is labelled as "SANTEN-fuse" by the researchers of the current study. The name was chosen to reflect the fact that the idea was sparked by the shape and construction of *santen*. It is written in all capital to signify the different structural functions between SANTEN-fuse and *santen*. Finally, the word 'fuse' is commonly used in the earthquake engineering field to illustrate a particular component that is used to dissipatethe energy of an earthquake, a process that is similar to how an electrical fuse cuts out an electrical current when there is an overload.

This research aims to investigate that the SANTEN-fuse can improve the performance of *rong-rongan* during an earthquake event-compared to the original *rong-rongan* structure.

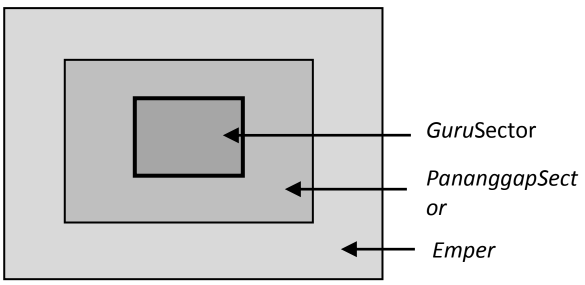


Figure 1a. Zonning in pendopo *Joglo's* plan (Cited from Prijotomo, 2005)

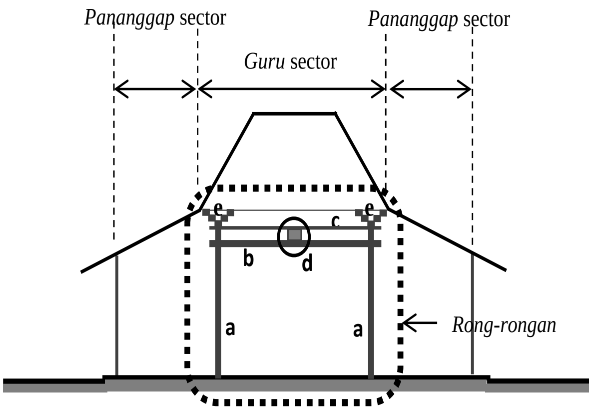
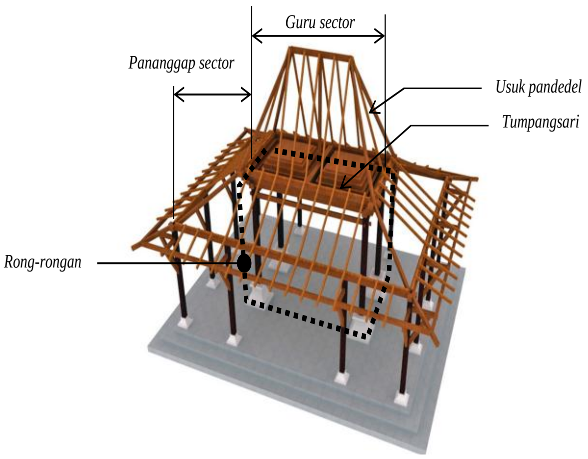
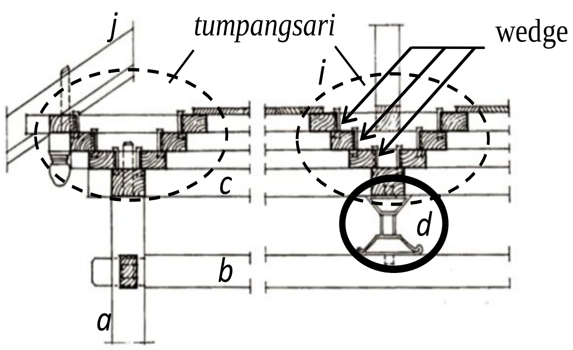


Figure 1b. The Section of *Pendopo Joglo* (Do not include the Figure of *Emper*)
a = *saka*, b = *sunduk*, c = *blandar*, d = *santen*,
e = *tumpangsari*



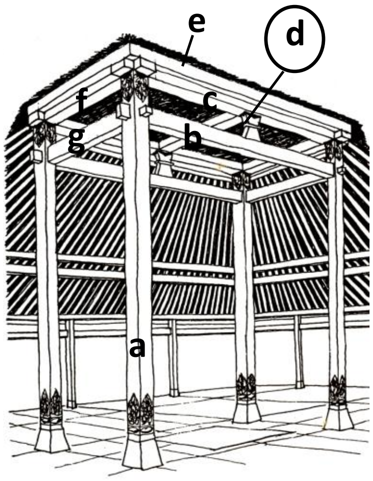
Source: http://achmad-jf.blogspot.com/2012/06/mengulas-sistem-struktur-joglo-dan-arti.html

Figure 1c. The Building Structure of *Joglo* (Excluding the Figure of *Emper*)



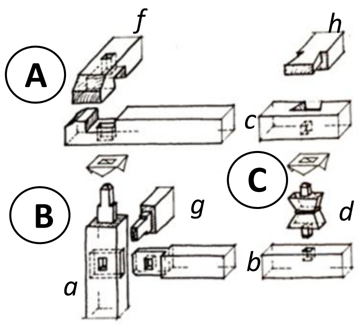
Source: Frick, 1997

Figure 2a. Section construction detail of *tumpangsari*
a = *saka*, b = *sunduk*, c = *blandar*, d = *santen*,
i = *tumpangsari*, j = *usuk pandedel*



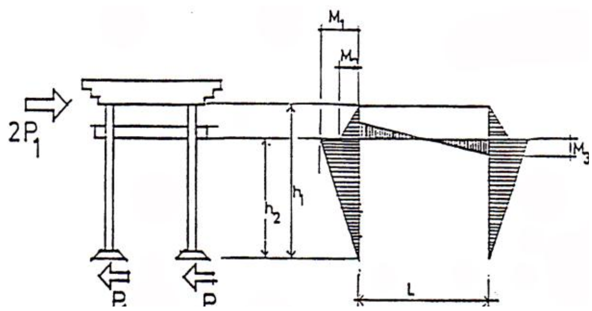
Source: Frick, 1997

Figure 2b. *Rong-rongan* structure
a = *saka,* b = *sunduk,* c = *blandar,* d = *santen,*
e = *tumpangsari,* f = *pangeret,* g = *kili*



Source: Frick, 1997

Figure 3. Connection construction detail of *saka-sunduk-kili* (a-b-g); *saka-blandar-pangeret* (a-c-f); *santen-blandar-sunduk* (d-c-b)
a = saka, b = sunduk, c = blandar, d = santen, f = kili, g = pangeret, h = dadapeksi)



Source: Ronald, 1987

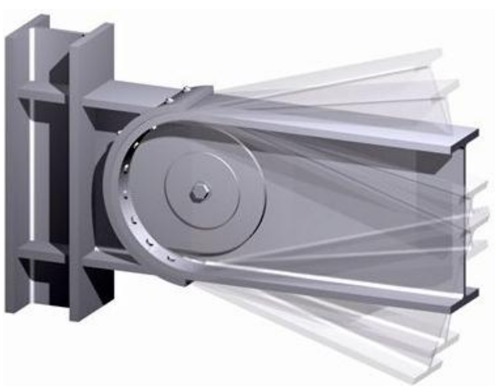
Gambar 4. Structural model and moment diagram of *rong-rongan*.

THEORETICAL FRAMEWORK

Previously, the author has done a preliminary research: "*Bisakah struktur rong-rongan rumah joglo hanya mengandalkan* SANTEN*?"* ("Can rong-rongan structure of *joglo* house only rely on SANTEN?") (Maer, 2012). In this research, the model of *rong-rongan* structure was modified to be a MRF Structure in which the stability and the rigidity were only supported by SANTEN. In the modified *rong-rongan* structure, the connections of *saka-sunduk* and *saka-kili* are pin joint connections. The previous research has proven that the modified structure model can stand with stability and has more or less the same rigidity as the original *rong-rongan* structure model (Maer, 2012).

In a different perspective, Dowrick (1977) offered a more economical solution, namely designing the structure in a way so as to perform the dissipation of the earthquake force through an inelastic behavior. When the structure receives a high magnitude earthquake force, some critical parts of the structural components performed the dissipation of energy (yielding), so that some of the earthquake force is released. But wood itself, which is commonly used in *Joglo* structures, is not ideal for this purpose (non ductile material)

Wada (2004) recommended the usage of an additional tool or component in the structural elements which are able to perform the energy dissipation without resulting in a permanent damage on the structural components, one of which is the Passive Energy Dissipation Control System (PEDCS). There are two PEDCS systems, which are: 1) damping which depends on friction (displacement), and 2) damping which depends on velocity. Pin-Fuse Joint™ (Figure 5), patented by SOM (SOM Journal 4, p 69, 2004), is one example of PEDCS system usage with rotation friction damping.



Source:http://designbythebay.com/wp-content/uploads/2010/12/Glamour_Shot.jpg

Figure 5. Pin-Fuse Joint ™

In this research, SANTEN's function is developed to be PEDCS, where its damping character is provided through translational sliding (friction damper). In order to test this proposed system, simulations were conducted by using the SAP2000 software. Ground acceleration consistent to Indonesian earthquake response spectrum is used as the seismic load, and non-linear time history analysis were conducted. In the simulation, the performance of the experimental model of *rong-rongan* structure was compared to that of the performance of the original model of *rong-rongan* structure. The parameters used for comparisons were: the lateral deflections at the top of the *rong-rongan*, the shear force at *sakaguru*, the normal force at *sakaguru*, and the bending moment at *sakaguru.*

In developing the SANTEN-fuse, there are some considerations, as follows: 1) the overall the shape is kept relatively similar to the original *santen*; 2) the construction detail must be simple so that it is easy to build and repair; and 3) strong wood material should be used. With those considerations in mind, the shape and construction of SANTEN-fuse is proposed. The wood material should be class 2 or better (NI 5/PKKI 1978), and bolt specification according to type A325, with a dimension of 12 mm. SANTEN-fuse is divided in the middle of its height; the top part is connected to *blandar/pangeret*; the bottom part is connected to *sunduk/kili*. The dimension and proportion of SANTEN-fuse is designed to perform mainly on resisting shear and not on bending moment. *Blandar/pangeret*, SANTEN-fuse, and *sunduk/kili* are assembled using pressure bolt which is placed in exactly at center of SANTEN-fuse's axis line.The hole for the pressure bolt on the top part of the SANTEN-fuse is designed to be loose in order to allow for movement space for the bolt. However, the hole for the pressure bolt on the bottom part of the SANTEN-fuse is designed to fit the bolt's diameter (Figure 6a1, 6a2, 6a3), and Figure 6b show SANTEN-fuse in slip position when receiving lateral shear force.

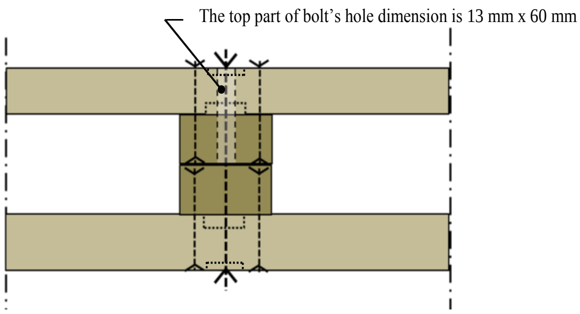


Figure 6a1. The front elevation of SANTEN-fuse construction

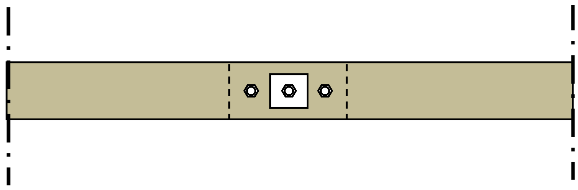


Figure 6a2. The plan of SANTEN-fuse construction

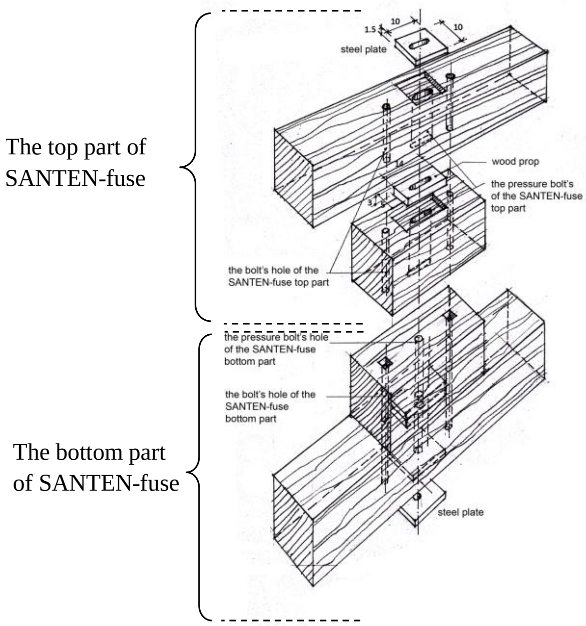


Figure 6a3. The perspektif of SANTEN-fuse construction

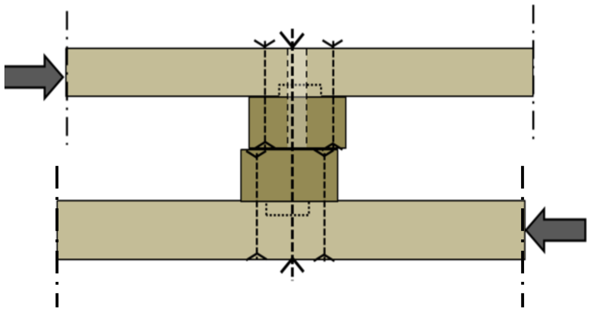


Figure 6b. *SANTEN-fuse*in slip condition

This research is an experimental quantitative research with *pendopo dalem* Yudonegaran in Yogyakarta as the case study. This research is using Ronald's (1987) research titled "*Joglo* building: A study of construction, proportion and structure of royal houses in Yogyakarta" as a source for the case study. Ronald (1987) studied several types of traditional Javanese buildings in Yogyakarta, one of which was the *pendopo dalem* Yudonegaran. The *pendopo dalem* Yudonegaran was selected as a case study in the present research because this particular *pendopo* received the biggest bending moment at the *sakaguru* compared to the other structures. In this

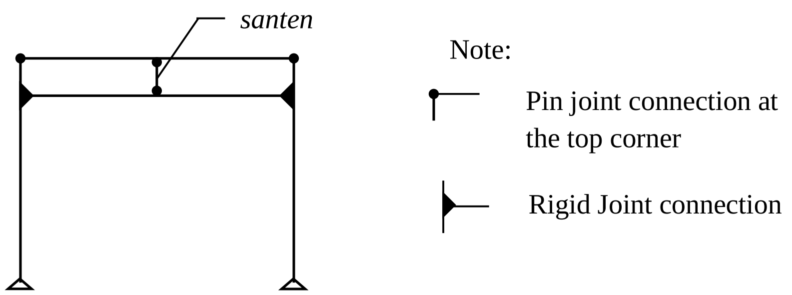


Figure 6a. Structure Model of $\mathbf{M_A}$

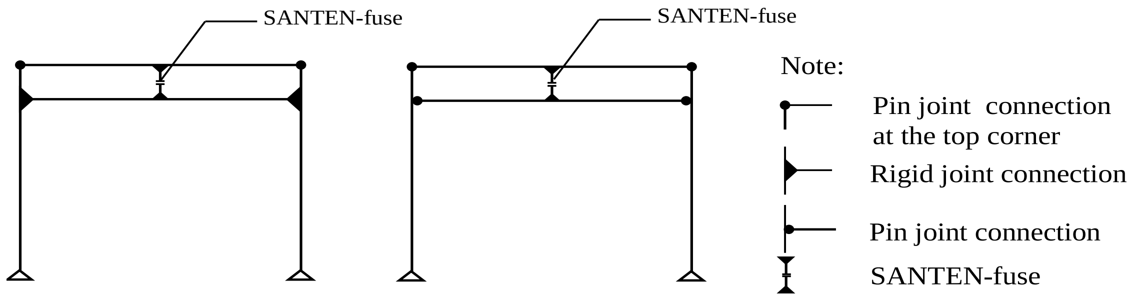


Figure 6a. Structure Model of $\mathbf{M_{SF\text{-}1}}$ **Figure 6b.** Structure Model of $\mathbf{M_{SF\text{-}2}}$

research, the performance between original model of *rong-rongan* structure $\mathbf{M_A}$ (Figure 6a) is compared with two types experiment models of *rong-rongan* structure $\mathbf{M_{SF\text{-}1}}$ dan $\mathbf{M_{SF\text{-}2}}$. $\mathbf{M_{SF\text{-}1}}$ is the original model of *rong-rongan* structure with SANTEN-fuse added (Figure 6b). $\mathbf{M_{SF\text{-}2}}$ is the modified model of *rong-rongan* structure (the connections of *saka-sunduk* and *saka-kili* are pin joint connections) with SANTEN-fuse added (Figure 6c).

All three models of structure $\mathbf{M_A}$, $\mathbf{M_{SF\text{-}1}}$and $\mathbf{M_{SF\text{-}2}}$ were analyzed using SAP2000 software. To each model was given modified north-south El Centro earthquake acceleration input to produce acceleration response spectrum which consistent with Yogyakarta earthquake area in soft soils according SNI 2002. In those three models, *rong-rongan* is presumed supporting the whole seismic forces. The research consist 2 stages:

A. Comparing the performance of $\mathbf{M_A}$ with$\mathbf{M_{SF\text{-}1}}$and $\mathbf{M_{SF\text{-}2}}$; and comparing the performance of $\mathbf{M_{SF\text{-}1}}$ with $\mathbf{M_{SF\text{-}2}}$.
B. Comparing the performance of $\mathbf{M_{SF\text{-}2}}$ + 1 pc SANTEN-fuse, $\mathbf{M_{SF\text{-}2}}$ +2 pcs SANTEN-fuse, $\mathbf{M_{SF\text{-}2}}$ + 3 pcs SANTEN-fuse, and $\mathbf{M_{SF\text{-}2}}$ + 4 pcs SANTEN-fuse.

Below are the variables which determine the damping level of the SANTEN-fuseon *rong-rongan* structure:

- Rigid zone, which positioned at the meeting point between the SANTEN-fuse with *blandar*/ *pangeret* and the SANTEN-fuse with *sunduk/kili*. Inside this rigid zone, there is no alteration of angle between the SANTEN-fuse with *blandar/ pangeret* and the SANTEN-fuse with *sunduk/kili*. The wide variable of rigid zone is set based on width to length ratio of the SANTEN-fuse(b/h) = 0.2, 0.5, and 1. Physically, rigid zone depends on SANTEN-fuse's dimension and construction section. The *SANTEN-fuse*'s dimension is determined based on: 1) the compressive strength of the wood towards the axial force of the pressure bolt; 2) the potential to perform rigid connecting behavior between *SANTEN- fuse* with *blandar/ pangeret*, and *sunduk/kili*; and 3) the ease in placing the bolt.
- Friction coefficient (μ–friction) at the interfaces of top-bottom of SANTEN-fuse. The friction coefficient was setas much as 0.2, 0.4 and 0.6.
- Axial compression force of SANTEN-fuse, which in turn depends on: 1) distributed load from the roof and *tumpangsari* on top of *blandar*; and 2) bolt tightening force (25%, 35%, 50%, and 75% of bolt allowable strength). If the roof structure and *tumpangsari* are set no resting on *blandar*, the axial compression force of the SANTEN-fuse comes only from bolt tightening force.
- Maximum slip (cm) is the amount of maximum slip depends on the width of rigid zone. In this research the maximum slip is expected to be less than 5 cm.

THE OBSERVATION RESULTS AND MODEL SIMULATION STUDY

The analysis result of Diagram-1 and Diagram-2 showed that $\mathbf{M_{SF-1}}$ and $\mathbf{M_{SF-2}}$ perform better than $\mathbf{M_A}$, however the performance development of $\mathbf{M_{SF-2}}$ towards $\mathbf{M_A}$ is far more significant compared with the performance development of $\mathbf{M_{SF-1}}$ towards $\mathbf{M_A}$. In those two tables, all deflection values (d) of *rong-rongan*, shear force (V) of *sakaguru*, normal force (N) of *sakaguru* and momen (M) of *sakaguru*which happened to $\mathbf{M_{SF-1}}$ and $\mathbf{M_{SF-2}}$ is smaller than that which happened to $\mathbf{M_A}$. Meanwhile, all of those values on $\mathbf{M_{SF-2}}$ are smaller than on $\mathbf{M_{SF-1}}$. This result shows that the performance of $\mathbf{M_{SF-2}}$ is the most optimum compared with $\mathbf{M_{SF-1}}$ and $\mathbf{M_A}$.

The dissimilarity between the two performances was caused by the fixed rigidity of $\mathbf{M_{SF-1}}$ which came from rigid joint connection between *sakaguru-sunduk-kili*, while $\mathbf{M_{SF-2}}$ structure rigidity only occurred because of the tightness of SANTEN-fuse (the μ-friction magnitude and axial force). When $\mathbf{M_{SF-1}}$'s SANTEN-fuse is tightened or loosened by increasing or decreasing the μ-friction and/or the axial force of SANTEN-fuse, the result of $\mathbf{M_{SF-1}}$ structure rigidity is not significant compared to $\mathbf{M_{SF-2}}$ in the same treatment. This resulted in the increase or decrease of the earthquake acceleration non linear time history response of $\mathbf{M_{SF-1}}$ to also be not significant compared to $\mathbf{M_{SF-2}}$.

The next interest is whether the different number of SANTEN-fuse caused significant effect towards $\mathbf{M_{SF-2}}$ performance. The analysis of the results is summarized and simplified in Graphic-1 which shows the relationship between the magnitude of V slip of SANTEN-fuse and the maximum slip of SANTEN-fuse in $\mathbf{M_{SF-2}}$ with 1 piece, 2 pieces, 3 pieces and 4 pieces SANTEN-fuse. Graphic-2 shows the relationship between the magnitude of V slip of SANTEN-fuse and maximum deflection at the top of *rong-rongan*of $\mathbf{M_{SF-2}}$ with 1 piece, 2 pieces, 3 pieces and 4 pieces SANTEN-fuse.

Observed is categorized in three V slip group magnitudes, namely: 1000 kgf V slip, approximately 1400 – 1500 kgf V slip, and 6000 kgf V slip. These three groups show a trend of inconsistencies on the magnitude of the maxium slip of SANTEN-fuse and the maximum deflectionof $\mathbf{M_{SF-2}}$. It seems that this phenomenon is the uniqueness of the non-linier structure: when $\mathbf{M_{SF-2}}$ is slipping, its condition becomes non-linear. In that condition, when $\mathbf{M_{SF-2}}$ receives non-linear time history earthquake acceleration, it is unclear whether it was the μ-friction, SANTEN-fuse axial force or the amount of SANTEN-fuse which significantly resulted in maximum slip, deflection at the top of *rong-rongan*, shear force on *sakaguru*, axial force on *sakaguru* and moment on *sakaguru*.

CONCLUSION

SANTEN-fuse addition can increase the performance of $\mathbf{M_{SF-1}}$ and $\mathbf{M_{SF-2}}$ structure models to be better than original structure model $\mathbf{M_A}$. The addition of SANTEN-fuse is more optimal if applied to *rong-rongan* structure with pin joint connection between *sakaguru-sunduk-kili* that is similar to modified *rong-rongan* structure ($\mathbf{M_{SF-2}}$) compared with rong-rongan structure with rigid joint between *sakaguru-sunduk kili* that is similar to original *rong-rongan* structure ($\mathbf{M_{SF-1}}$). The number/amount of SANTEN-fuse is not significant in determining the structure model $\mathbf{M_{SF-2}}$ result level.

RECOMMENDATIONS

The usage of SANTEN-fuse is recommended especially for modified *rong-rongan* structure where the connection between *sakaguru-sunduk-kili* uses pin joint connection. The addition of SANTEN-fuse can be applied to both the new *pendopo joglo* construction and the existing *pendopo joglo* to improve its performance. However, special designed construction of SANTEN-fuse (SANTEN-fuse dimension, bolt dimension, tightness level of bolt) needs to be done for each *pendopo joglo* building and different earthquake area.

The addition of SANTEN-fuse to existing *pendopo joglo* without changing joint construction between *sakaguru-sunduk-kili* can be done although the result will be less effective than if the construction joint between *sakaguru-sunduk-kili* is changed into pin joint.

Results from this study have shown that it is possible to create an"earthquake friendly" structure in *joglo* buldings. It is recommended that future research in this field should focus on:

- The effect of changing the structural function of *santen* to SANTEN-fuse in relation to the architectural meaning of *pendopo Joglo*.
- Detailed construction design of joint between *sakaguru-sunduk-kili* which is changed into pin joint.
- The bolt tightening application for SANTEN-fuse is still limited to this research and cannot be generalized for actual use yet. Further research should be conducted to formulate the conversion table of bolt torque moment (the result of bolt tightening with torque wrench) to axial force.

- This research is developed based on secondary literature data; therefore, there is a possibility that some of the experimental conditions may not reflect real-life situations. Thus, this also opens an opportunity for further field study.

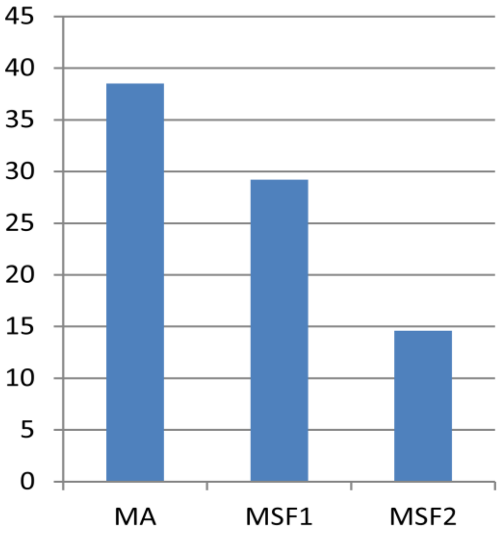


Diagram 1. Maximum Deflection on the models: MA, MSF-1, MSF-2

Note:
The vertical axis = maximum deflection at the top of *rong-rongan*, in cm. The horizontal axis = the type of the models

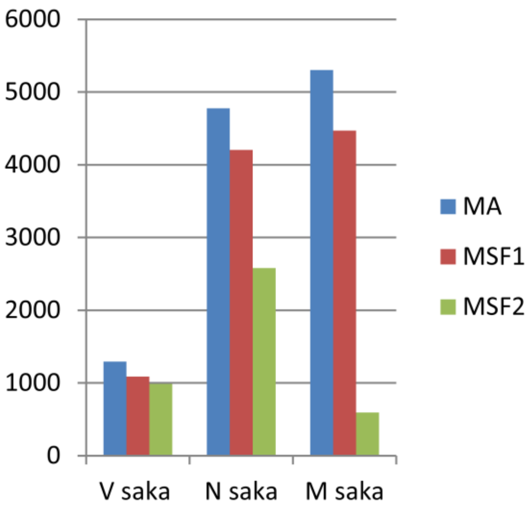
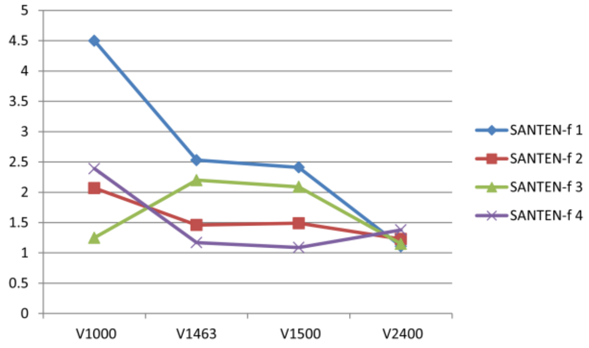


Diagram 2. Maximum Shear Force of *Sakaguru* (V *saka*), Axial Force of *Sakaguru* (N *saka*), and Moment of *Sakaguru* (M *saka*) on MA, MSF-1, MSF-2

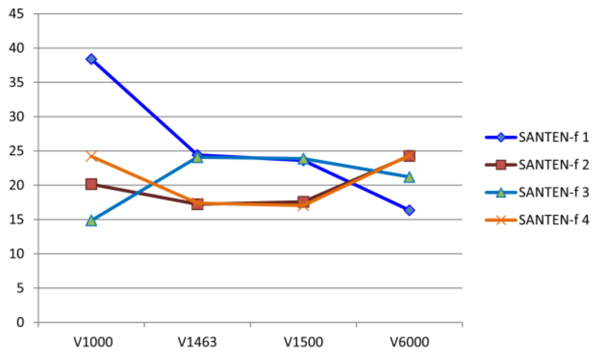
Note:
The vertical axis = the magnitude of shear force (V, in kgf), axial force (N, in kgf), Moment M, in kgf m) of *sakaguru*



Graphic 1. Maksimum Slip of SANTEN-fuse vs V slip, for µ Friction = 0.4, On M_{SF-2} with 1 pcs., 2 pcs., 3 pcs., 4 pcs. SANTEN-fuse

Note:

- The vertikal axis = maximum slip in cm
- The horizontal axis = V slip in kgf; V 1000 = the magnitude of V slip = 1000 kgf, V 1463 = the magnitude of V slip = 1463 kgf,V 1500 = the magnitude of V slip = 1500 kgf,V 2400 = the magnitude of V slip = 2400kgf.
- SANTEN-f1 = the amount of SANTEN-fuse is 1 pcs., SANTEN-f2 = the amount of SANTEN-fuse is 2 pcs., SANTEN-f3 = the amount of SANTEN-fuse is 3 pcs., SANTEN-f4 = the amount of SANTEN-fuse is 4 pcs.



Graphic 2. Maksimum Top Deflection vs V slip, for µ Friction = 0.4, On M_{SF-2} with 1 pcs, 2 pcs., 3 pcs., 4 pcs. SANTEN-fuse

Note:

- The vertical axis = maximumtop deflection in cm
- The horizontal axis = V slip in kgf;V 1000 = the magnitude of V slip = 1000 kgf, V 1463 = the magnitude of V slip = 1463 kgf, V 1500 = the magnitude of V slip = 1500 kgf, V 6000 = the magnitude of V slip = 6000 kgf.
- SANTEN-f1 = the amount of SANTEN-fuse is 1 pcs., SANTEN-f2 = the amount of SANTEN-fuse is 2 pcs., SANTEN-f3 = the amount of SANTEN-fuse is 3 pcs., SANTEN-f4 = the amount of SANTEN-fuse is 4 pcs.

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