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Stability of Gunung Tigo Slope: Pore-Pressure Effects Analysis

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Abstract

Landslide at Gunung Tigo-Cumanak in Pariaman due to the Padang earthquake in 2009 has buried three underneath villages. This earthquake induced landslide also killed hundreds people and demolished access roads. This paper elaborates the landslide back analysis with focus on the increasing excess pore-pressure. Field survey has been conducted as well as tests of soil properties on the location to get the slope geometric and soil mechanics data. Based on results of the field survey and soil test, the slope stability analyses then are performed. The special aim of this simulation is to elaborate the effect of pore-pressure on slope stability. The landslide analyses were done by considering the static and dynamic loads. The dynamic analyses are considering the earthquake load of Padang in 2009. The results of this study presented in the terms of pore-pressure and safety factor relationship for both static and dynamic loads. This study is very useful to understand the effect increased pore-pressure induced by an earthquake on slope stability.

Keywords: earthquake; landslide; dynamic analysis; mitigation.

1. INTRODUCTION

Earthquakes in some places can trigger landslides such have been reported [1] and [2]. The earthquake triggered landslides can be generally caused by the additional inertia forces or the increased pore water pressure in the slope soil mass. Both of them result the decreasing slope stability in terms of factor of safety.

Strong earthquakes often result in liquefaction. Liquefaction is a phenomenon the change of the soil from the solid state into a liquid state. This phenomenon caused by the increase in soil pore water pressure that exceeds the contact stress in the soil, so that the effective stress in the soil theoretically becomes zero. Effective stress is the difference between the total stress and the pore water pressure that can be written as follows:

$$\sigma' = \sigma - u \tag{1}$$

Where:

σ' = effective stress

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σ = total stress, and
u = pore water pressure

Based on the experiences of liquefaction testing conducted by the authors [3] as well as other researchers [4], there are not all seismic motions can result liquefaction. Liquefaction is influenced by some physical and mechanical factors of soil. The most factors that effect the liquefaction are the strength of the seismic motion which is represented by acceleration, **a** and mean soil particle size, D_{50}. However, the increase in pore water pressure more than 70% can be considered to cause liquefaction [4].

During Padang earthquake in 2009, there has been reported a huge landslide in Gunung Tigo - Pariaman. The landslide had buried three villages below, killed hundreds of people and destroyed access roads (Figure 1) [5]. Based on field observations following the earthquake in Padang, 2009, in The Gunung Tigo has found flow of water at several point where have experienced catastrophic landslide. This evidence indicates that the landslide on the slope of Gunung Tigo was also caused by an increase in pore water. In this paper, the location of Gunung Tigo landslide is taken as a case study to demonstrate the effect of pore water pressure during the earthquake to slope stability.

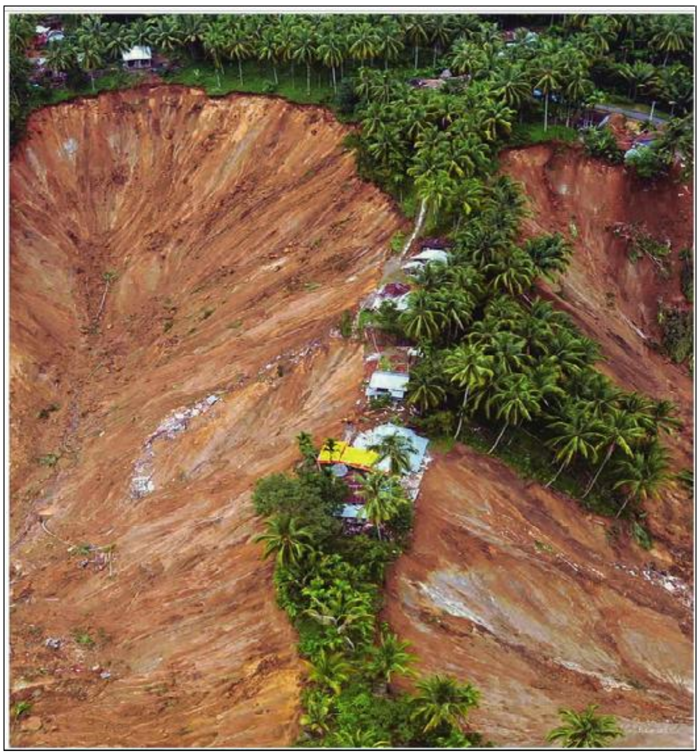

Fig. 1. Gunung Tigo landslide

2. SLOPE STABILITY ANALYSIS

In the soil mechanics field, the shear soil strength can be expressed in terms of effective stress and cohesion in the soil which is written as follows:

$$\tau = \sigma \tan(\phi) + c \tag{2}$$

Where:
τ = shear stress
σ = normal stress
c and ϕ = cohesion and internal friction angle of the soil, respectively

Increase in pore water pressure can reduce the effective strength of the soil, such that the shear strength is also reduced. In general for the slopes in static condition, the stability is expressed as the ratio between the shear resistance of soil at failure plane to the diving shear stress which is an accumulation of forces that act on the landslides (Fig. 2). The ratio of the resistance and the driving stresses is known as a safety factor that is written as follows:

$$SF = \tau / \tau_m \tag{3}$$

Where:
SF = safety factor
τ = shear resistance, and
τ_m = driving stress that caused the landslide

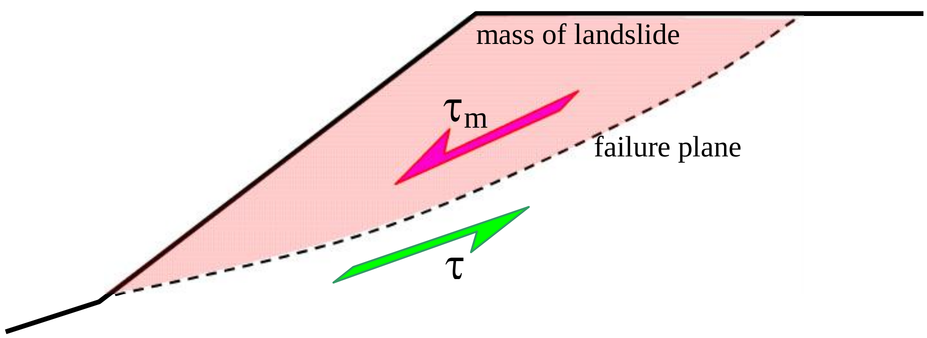

Fig.2. Landslide mechanism

For the special case where the slopes have sufficient saturated soil with certain ground water level and experiencing the earthquake such that the pore water pressure is increased, the amount of forces will effect the factor of safety (Fig. 3). Those forces will increase the driving stress and on the other hand will reduce the stress resistance of the slope. The safety factor in this condition is then written in the following general equation:

$$SF_d = \tau_d / \tau_{md} \tag{4}$$

Where:
SF_d = dynamic safety factor,
τ_{md} = dynamic pressure caused landslides
$= \tau_m + f(a)$
τ_d = dynamic shearing resistance
$= \tau - f(u, \Delta u)$
Δu = increase in pore water pressure due to seismic
f (a) = inertia force caused by the earthquake with acceleration a
f (u, Δu) = forces as function of pore water pressure

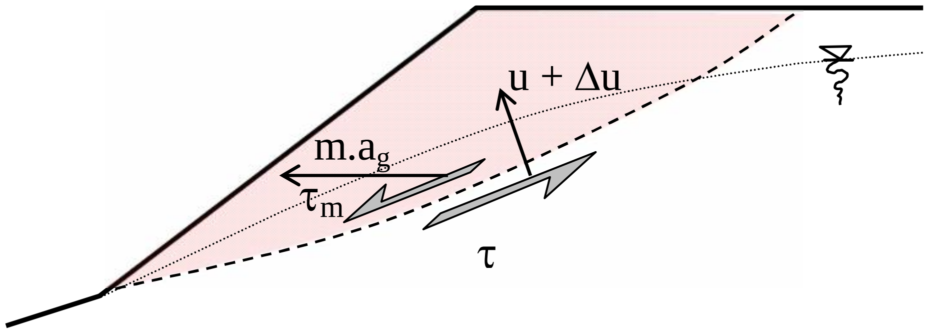

Fig.3. Dynamic landslide mechanism

3. ANALYSIS AND RESULTS

Field investigation on the location of the Gunung Tigo landslide in year 2009 has been done. This field study is intended to gain the geometry of the slope along with soil data for slope stability analysis. The test results of soil samples in laboratory are shown in Table 1. That parameter values the are used in the calculation of slope stability analysis.

Table 1. Tsunami induced forces

Parameter	Value	Unit
Unit weight, g =	12.5	(kN/m^3)
Cohesion, c =	18	(kN/m^2)
Internal friction angel, ϕ =	20	(degree)

Based on observations in the field, the slopes of Gunung Tigo has an average slope of 40 degrees. Failure plane of the slope located at a depth of 1m to 2m from the slope surface. Saturated soil at failure plane field has a thickness of about 50 cm. Based on these data then a series of slope stability analysis are performed with taking into account the increase in pore water pressure. The calculation results are showed in Fig. 4 and 5 below. In normal condition, the static safety factor of the slope SF is 1.9 and at the earthquake load the safety factor, SF_d is 1.2

Based on Fig. 4 which shows the relationship between the increase pore water pressure and stresses in the soil, it can be seen that the effective stress will be decreased in such a way to zero at when the increase in pore water reaches about twice of the initial one. Theoretically at this time the soil on the grained soil type of slope will suffer from liquefaction.

Fig. 5 shows the increase pore water pressure respect to the slope safety factor. Slope safety factor decreases with the increasing pore water pressure. Slope safety factor value is in a critical condition that is close to 1.0 when the pore water pressure has reached almost twice the initial conditions. In fact, the slope of Gunung Tigo has collapsed, it is theoretically possible since non-homogeneous soil in many spots. At that spots the cohesion that is less than the results of this test, will cause the slope failure. The failure at one point will trigger the adjacent point at the slope. It continues such that the overall slope of Gunung Tigo were collapse.

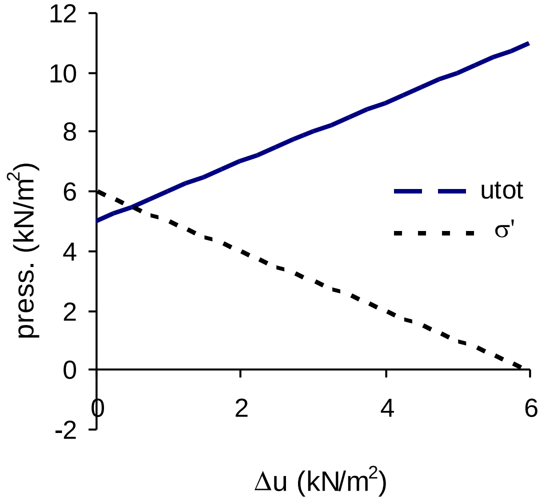

Fig. 4. The increased pore water pressure versus stress in soil mass

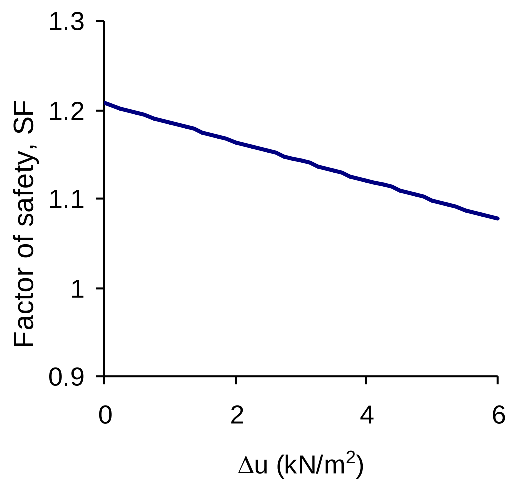

Fig. 5. The increased pore water pressure versus factor of safety

CONCLUSIONS

The increase in pore water pressure in saturated soil mass can be caused by an earthquake. Although the liquefaction condition is not reached, but the increase in pore water pressure may affect the stability of the slope. In this paper has shown the increased pore water pressure to influence on the reducing the value of slope factor of safety with the example in slope failure at Guning Tigo - Pariaman. It has shown as well that the soil parameters were very significant in contributing to the factor of safety of slope is cohesion on the soil.

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Tsunami Shelter In Padang By Utilization of The Advantage of Composite Structure Material Made of H-section Steel and Reinforced Concrete

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Abstract

Since Padang City is defined to have the most tsunami risk in Indonesia, there are many studies have been done to mitigate the tsunami disaster. One of the mitigation action for tsunamis is done by constructing tsunami shelters. The tsunami shelter structure must be designed to withstand during a big earthquake which occurred at first before the tsunami. Further, the structure should be able to restrain the tsunami attack along with the tsunami induced forces. Reinforced concrete is a material that has been widely used to build the existing shelter. This study describes the use of the composite material consist of H-section steel and reinforced concrete for the main structure of the tsunami shelter in Padang. Three-dimensional finite element method is used as the numerical tool to calculate the internal forces in the structure of the shelter. Based on the results of this study, it can be elaborated the advantages of the composite materials compared to the reinforced concrete for earthquake and tsunami resistant structures. One of those advantages is the relatively slim structure which resulting relatively smaller internal forces. The composite structure also requires relatively more economic foundation system compared to the reinforced concrete structure.

Keywords: earthquake, tsunami, composite, shelter, mitigation.

1. INTRODUCTION

Based on tsunami experiences in the past, the tsunami hazard can be categorized into two terms that are short- distance (local) and long-distance tsunamis. As the general tsunamis that occurred in Indonesia, the tsunami threat in the city of Padang is coming in term of local tsunami. The tsunami sources where is very likely attach Padang city are located at subduction of the Eurosia plate and the Australian plate on the west side of the Sumatra island. From this locations, the estimated arrival time of a local tsunami is about 30 minutes following the triggering earthquake. The long-distance tsunamis that occurred 1 to 8 hours after the earthquake which are not felt by Padang people, are having a little possibility to damage Padang city.

The number of people of Padang which affected by tsunami are more than 333,000. Many experts have conducted and published the a numerical simulation risults of the Padang tsunami, one of them is studied by Borrero et al, in 2006 [1]. Based on the simulation results, it can be concluded two important points. First, the physical properties of the tsunami wave in terms of height and inundation. The high of tsunami wave that predicted to reach the city of Padang is about 3-

6m. For the purposes of building a temporary evacuation planning was taken by 5m. This altitude is very dangerous and can be devastated buildings in the city and claimed hundreds of thousands of residents of the city of Padang.

Second, tsunami arrival time after the earthquake. For the city of Padang the predicted tsunami arrival time is 30 minutes. The earthquake locus is around the Mentawai islands. This time is enough to evacuate people from the Padang shore area to the distant area as far as 2 to 3 km. However, for the area in where there is no designed evacuation access, this time may be a limit to determine the vertical evacuation to the tsunami shelter.

Padang has created a tsunami hazard map in which divides the city into three zones with different colors; red, green and yellow (see Fig. 1). The red zone is the lower area and close to the beach which highly affected by the tsunami. The green zone is the higher land and far from the beach so it is categorization as tsunami safe area. The yellow zone is the area between red and green which likely to be affected by the tsunami.

Historically, the Padang City was established by Dutch colonialism in beginning of 1900. The city is then grew without any clear planning. As the result, the residential settlement was developed rapidly in the area of the seashore near by in where it is now known as the red zone. After the Aceh tsunami in 2004 the residential development in the shore near was stopped. However the number people living in the red zone is still very large.

There are two options of mitigation measures were taken by Padang government. First is by developing horizontal evacuation accesses towards the safe zone and second is constructing vertical shelters in the red zone. For the area with the limited land to build the access, the temporary evacuation shelter is the choice. An evacuation shelter is in the term of building that should initially be able to resist the earthquake and than must withstand the tsunami attack.

Fig. 1. Tsunami hazard map of Padang city

The study on tsunami shelter in the city of Padang has been made since the tsunami in Aceh. An assessment of the vulnerability of buildings in the Padang city due to tsunami has done [2]. This study is aimed to assess the possibility of buildings in the city to be used in chase of tsunami. The buildings that might survive during earthquake, further assessed to be used as a tsunami temporary shelter. In this study the building vulnerabilities were assessed based on several indirect criteria. The particular chosen building must be checked further in term of its strength for the tsunami shelter.

2. STRUCTURAL ANALYSIS FOR TSUNAMI SHELTER

In addition to the historical evidence, the research on a possibility of tsunami in the city of Padang has been carried out based on similar experiences in the movement of Bengkulu segment in 2007 [3]. The results of these studies indicated that the 2007 tsunami which reached the height up to 3.6m in Bengkulu might reached 1.6m in Padang. However, since there is a dike along the Padang beach with the hight of 2m, the tsunami impact was not felt. However for tsunami height more than 5m, the severe damage may occur in the Padang city. Therefore the appropriate evacuation will greatly help the avoid or reduce tsunami victims.

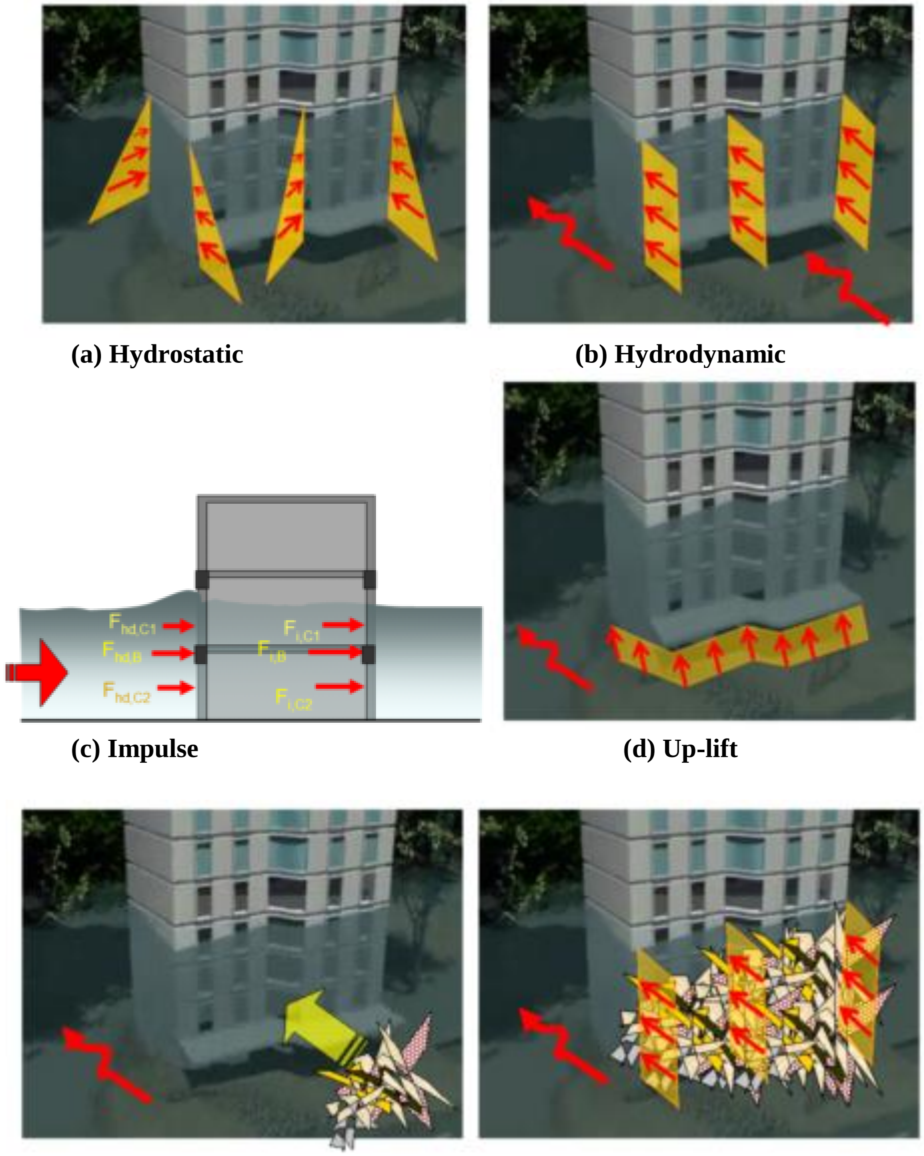
The study of the tsunami safe structure in Thailand has been done as a result of the Aceh tsunami in 2004, which reached the country [4]. Based on the possibility of tsunami attack on the building structure, then the structural analysis the shelter structure divided into two different criteria; First the shelter in the area where large debris is highly suspected and the shelter in the area where large debris is impossible. Furthermore, based on those criteria the guidance of tsunami safe structural analysis was proposed. The tsunami safe structures are required to have tolerance for minor damage. The structure which is not expected to be attacked by debris must have a good connection between the inside and outside elements. While the structure is estimated to be attacked by debris, must be planned with special damping connection between the outside and inside elements of the building.

For the purposes of tsunami shelter, it has been a guidance for the tsunami induced loads that work on the structures [5]. Meanwhile the guidance regarding the room function and additional facilities are stated in the additional code [6]. The tsunami induced forces in that code are adopted in this study. In this study, the shelter structure is made of steel-concrete composite as described in the following sections. The tsunami induced forces on the structure are hydrostatic, hydrodynamic, impulse, floating (up-lift), impact and damming of debris. Each load formula is written in Table 1 and illustrated in Fig. 2 (a) to (f).

Table 1. Tsunami induced forces

No.	Force	Formula
1	Hydrostatic	$F_{hs} = {}^{1}/_{2}\ \rho_a\ g\ b_d\ (h_{ds})^2$
2	Hydrodynamic	$F_{hd} = {}^{1}/_{2}\ C_d\ \rho_a\ g\ b_d\ (h_{ds}\,u^2)_{max}$
3	Impulse	$F_i = 1.5\ F_{hd}$
4	Up-lift	$Fa = \rho_a\ g\ A_t\ h_t$
5	Impact	$Fa = C\ u_{max}\ (k\ m)^{0.5}$
6	Damming	$F_{hd} = {}^{1}/_{2}\ C_d\ \rho_a\ B_d\ (h_{ds}\,u^2)_{max}$

Where
a = sediment-salty water density (1100 kg/m3)
g = gravity acceleration (9.81 m/dt2)
bd = wall width
hds = tsunami hight
Cd = drag constant (2.0 is suggested)
u = water velocity
At = floor area
ht = the hight of trapped air
C = mass constant (2.0 is suggested)
umax = debris velocity
k = stiffness of the debris
m = mass of the debris
h = dam hight
Bd = dam width



(a) Hydrostatic **(b) Hydrodynamic**

(c) Impulse **(d) Up-lift**

(e) Impact **(f) Damming**

Fig. 2. Illustration of tsunami induced forces

The forces are then applied to the structural elements that to withstand the loads of tsunami to get the internal forces of the structure. The structural analysis of internal forces is done using numeric tool based on finite element method.

3. ANALYSIS AND RESULTS

The advantages of steel-concrete composite structures here is applied to the building for tsunami shelters in the city of Padang. The building is expected to constructed in the red zone with a height tsunami of 5m. The building location is about 2 km away from the shore near by. The building is on the site with the depth of hard soil layer up to 30m from the surface and classified as soft soil sites. On the top floor of the building, there is planned a special level for helicopter (helipad). The preliminary analyzed to obtain initial dimensions of the structural elements of the building is done based on its function and location. The column dimensions of the building are; 3.0m-30x30cm, 3.8m-40x40cm and 4.0m - 60x60cm for length-cross section of the first, second and third level respectively. The finite element model of the structure is shown in Fig. 3.

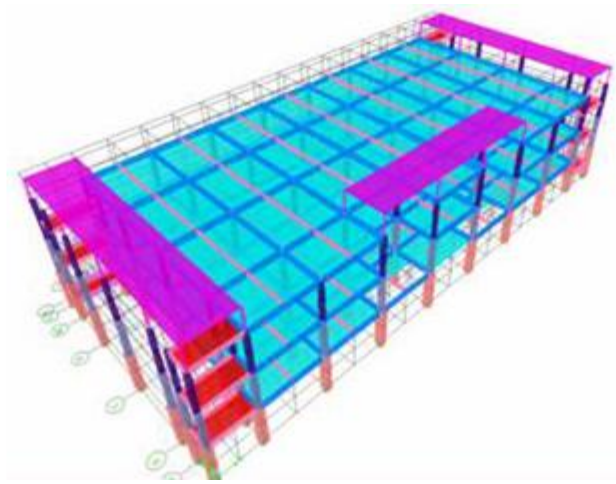


Fig. 3. The finite element of the shelter structure

Further, analysis of the internal forces in the structure elements of the building is done by combining dead loads, live loads and seismic loads to get the maximum forces. Based on those internal forces, the steel and concrete composite structure is estimate to obtained the appropriate profiles. The maximum combination forces in this analysis stage are; 1st column has the axial force of P = 808 kN, moment of M = 241 kNm and shear force of N = 95 kN for first column. The calculation result obtained the composite dimensions H -300.300.10.15 for column of 3rd and 2nd floor and it is H-350.350.12.19 for the 1st floor columns as shown in Fig. 4. This dimensions are then used for the structural analysis under the tsunami loads.

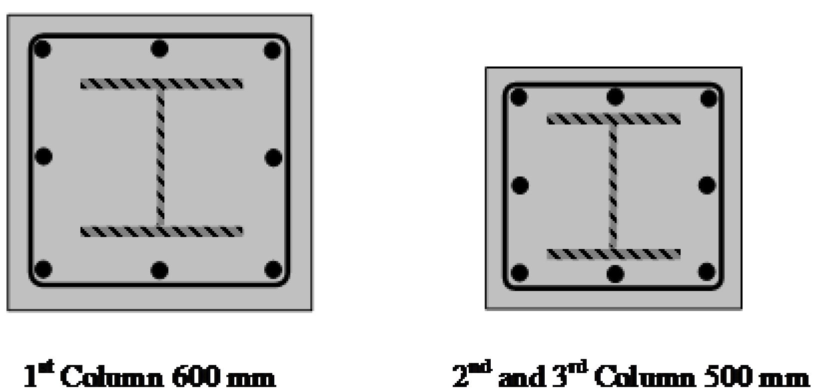


Fig. 4. The column cross sections

To gain an effective structure, the walls of the 1st and 2nd floors of the building is designed in such a way collapse in case of tsunami. This concept have an advantage to obtain smaller tsunami forces on the structure. Then, based on the analysis of the structure due to the tsunami induced forces it is obtained the maximum combination of the axial force P = 300 kN and moments M = 460 kNm and normal force N = 361 kN. Those internal forces are then combined with other internal forces that works in the structure according to the following rules (FEMA, 2012):

$$\text{Load Combination} : 1.2\ D + 1.0\ Ts + 1.0\ Lr + 0.25\ L \tag{1}$$

where D is the dead load, Ts is the maximum tsunami load, Lr is the refuge load, and L is the other live load.

Based on calculations using the formula above, it shows that the combined forces with the tsunami load is smaller than the maximum capacity of the existing columns. It can be concluded that the shelter can withstand the tsunami.

Compared to the use of conventional reinforced concrete structure, the dimensions of reinforce concrete structure will be larger. This is initially due to the thickness of the floor plate to meet the standard regulations. For the example, thickness of concrete on the floor plate is 10cm for composite, while for conventional reinforced the minimum required thickness is 12cm. The reinforced concrete plate has increased the floor mass of at least 20%. This in turn in the need of additional dimension to the other supporting elements, such as beams and columns as well as the foundation. Finally, the increasing size of the beams and columns will also increase in the forces caused by the tsunami.

CONCLUSIONS

Padang city historically has experienced several tsunami. The Bengkulu earthquake in 2007, the tsunami waves have reached the Padang city with the maximum height of less than 2m. In the future there most likely will be tsunami waves attack and devastate the Padang city with the height up to 5m. So it is necessary to prepare a mitigation actions to evacuate people by both horizontally and vertically ways.

In this study has successfully been designed a tsunami shelter in the form of a 3-storey building. The shelter building is made of concrete-steel composite material. Initially, the building is planned to be resistant to combined forces of static and earthquake loads. Furthermore, the loads of tsunami induced on the building are combined with other internal forces.

The composite structure used for the building shelter is considered to be more efficient than ordinary reinforced concrete material. This is due to the relatively small dimensions of the structure will result in smaller forces in anyway.

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