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Loss of Life Estimation using Life Safety Model for Dam Breach Flood Disaster in Malaysia

Fatin Faiqa Norkhairi[1*], Hasril Hasini[1], Sivadass Thiruchelvam[1], Nur Irmawati Om[1]

[1]Fluid Dynamics and Disaster Risk Reduction Research Group, College of Engineering,
Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000, Kajang, Selangor, MALAYSIA

*Corresponding Author

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Abstract: The need for an emergency disaster management related to dam has risen up in recent years. This is due to uncertainties in global weather predictions which also affect local Malaysian area. With unpredictable prolonged rainy weather, concerns on events that could lead to flooding has triggered the authority to review the evacuation strategies in critical locations. This paper describes an investigation on the effect of early warning system and people response delay to the rate of fatality in the event of flooding due to dam breach. The Life Safety Model is utilized as a tool for the simulation of people vehicle and building response to 2D hydraulic flow of the river originated from the dam. The study area is based on Kenyir Dam and its surrounding vicinity. A number of scenarios are simulated namely cases with and without early warning system. For the case with early warning system, different triggering time is also investigated. On top of that, the effect of people response delay to the warning system is simulated. It was found that early warning system plays a critical role in reducing the number of fatalities due to flooding. Equally important is the time taken for the community to start evacuating when triggered by the early warning system. From the result LSM, optimum evacuation parameters could be identified and used for the purpose of design, planning and implementation of local emergency evacuation plan in the event of dam-related flooding.

Keywords: Flood, dam breach, loss of life, agent-based model, life safety model

1. Introduction

Nowadays, emergency plan in the field of dam safety has become one of the increasing attention in risk management. The low frequency but high vulnerability dam breach causes great impact at the downstream area of the dam. Although the dam construction can act as a flood barrier, a sudden flood from dam breach can give a huge hit. The impact of the dam breach that come together with the huge wave of flood may cause loss of life and destroy all the structures at the downstream. There are many causes of dam breach in the world such as overtopping, foundation defects, cracking, inadequate maintenance and upkeep and also piping (Officials, 2019).

One of the famous dam breach in history is Teton Dam which located in southeastern Idaho on 5th June 1976. During the event, the dam release more than one million cubic meter (m^3) of water and washed away all the properties downstream with 11 people loss their life. Due to this dam disaster, Dam Safety program is established and have been used as dam safety model from all around the world (Reclamation, 2016). In Southeast Asia, the Xe-Pian Xe-Namnoy dam in Laos collapsed on 23 July 2018 due to heavy monsoon rains. The dam released half billion cubic meter (m^3) of water causing an unknown number loss their life and others were missing (Program, 2018). On 1st May 2020, the failure

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* *Corresponding Author: fatinfaiqa.norkhairi@tnb.com.my*

of Sarboda Dam in Uzbekistan has caused the dam wall to collapsed partially and release 500 million cubic meter (m^3) of water in the early hour of the day. Six people loss their life and 110, 000 residents were evacuated to the safe area and affected 35,000 hectares of land in Uzbekistan and Kazakhstan (Service, 2020; Simonov, 2020). The failure of the dam is reported due to heavy rain and strong wind. From the series of history of dam breach in the world, it is noticeable that the great impact would occur at downstream. The most notable impact of dam failure is loss of life and properties damages which give a benchmark for the severity of the disaster. Thus, with the developing technologies nowadays, a better emergency action plan can be improved as the dam breach can be simulated as well as the possibility of loss of life at the downstream could be estimated. In case to estimate the loss of life, several methods were developed to help the researchers to improve emergency plan due to dam breach. The accurate estimation of loss of life is important to strategize the risk reduction thus can determine the consequences and risk level (Jonkman & Vrijling, 2008).

Several types of methods were developed to help researcher to estimate the loss of life. The loss of life model can be categorized into two (Rahman, 2016) which are the empirical model and agent-based model. The empirical model uses statistical information from historical events to determine the relation between the flood characteristics and the people that have high risk to loss their life due to flood. In agent-based model, a simulation based on the physical process occurring during the flood event is carried out. The model used various input such as flood characteristics (depth and velocity) which can correlate with the flood exposure such as person at risk (PAR), structural of building, evacuation time and warning time.

A number of works on this field is available from the open literature. Some of the prominent ones which focusing the loss of life model based on the empirical and agent based models is summarized in Table 1.

Table 1 - List of loss of life model (Rahman, 2016)

The Empirical Model	Agent Based Model
Ayyaaswamy et al.	LIFEsim Model (McClelland, Bowles and Aboelata 2000-2005)
Pate'- Cornell and Tagaras	HECFIA (Hydrologic Engineering Centre-Flood Impact Analysis)
Standard/ FEMA Model - Institute for Water Resources (Lee et al., 1986)	Life Safety Model (LSM) British Columbia Hydro / HR Wallingford Life Safety Model (Assaf and Hartford 2002, Jonstone et al., 2005)
Standard/ FEMA Model - Institute for Water Resources (Lee et al., 1986)	
United States Bureau of Reclamation (Brown and Graham 1988; McClelland and Bowes, 2002)	
Dekay and McClelland (Bureau of Reclamation, 1993)	
Graham (1999)	
British Columbia Hydro Loss of Life Model (Hartford et al. 1997)	
RCEM- Reclamation Consequences Estimating Methodology (USBR, 2014)	

This paper presents the application of agent based model namely Life Safety Model (LSM) to estimate the number of loss of life in due to dam breach event in Malaysia. Although Malaysia has never experienced the impact of dam breach, the incident that happened around the world especially in Southeast Asia increases the level of concern on the potential of unprecedented event in the country. Despite very low probability of such event to occur, the risk must be considered as crucial and thus preparatory measure for disaster management must be made. The result from this study helps to improve dam safety risk assessment and management. On top of that, the outcome can quantify the risk and decision making for any event related to dams. Moving together with the technologies in the world, the improvements on loss of life estimation and become one of the increasing requirements to estimate the number of fatalities (Lence et al., 2011).

2. Functionality of Life Safety Model (LSM)

Life Safety Model or known as LSM is an agent based model, able to quantify the dam risk assessment. The agent based model is a model that can capture the behavior of the people, building, vehicles and other receptor model in an environment. By using the concept of agent based model, LSM is able to integrate the flood wave and receptor such as people, building and vehicles which result to the 'fate' of the receptor. Moving from the empirical model to agent based model, the LSM focused on the impact of the receptor in the floodplain in a way of fatalities, injuries, building destroyed and vehicles toppled. LSM requires a set of crucial data and information based on the actual condition of the receptors in a regions of interest. These information include:

- Flood depth and velocities which is represented in two dimensional (2D) hydrodynamic model of flood
- Individual and group of people location, building location and vehicles. This is the time-varying properties which include the abilities of the properties to withstand the impact of flood wave.
- Road network and other pathways for evacuation process. People will use the road network or footpath depending on the evacuation mode to the safe haven.
- Flood warning dissemination. Through warning evacuation, people response towards the warning siren can be model in LSM.

These information is used in a set of dynamics equations to predict the outcome which eventually leads to the estimation of the number of loss of life and dynamic computer-graphic visualizations. To obtain a weighted number of losses, multiple runs of simulation is conducted to present a valuable number of loss of life. The dynamic visualization or animation helps the analysts to liken the emergency situations with and without planning and mitigation process (Johnstone et al., 2005; Lence et al., 2011). In general, the architecture of LSM is shown in Figure 1. The framework can be divided into three stages namely the Input, the main LSM solver and the Output or result visualization. At the pre-processing stage, 2D hydraulic data from dam break, river flooding or other disaster scenarios are fed into the solver. These data are usually supplied in the form of flow speed and river depth obtained from prior 2D hydraulic simulation. In addition, all the required information on the populations, buildings, vehicles etc. in the regions of interest are also outlined for integration with the 2D hydraulic data.

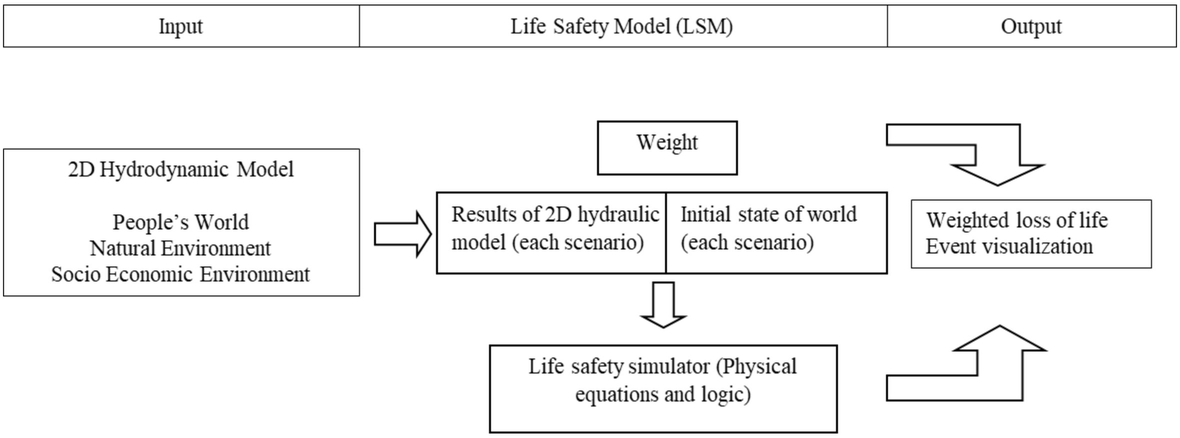

Fig. 1 - Architecture of Life Safety Model
(Johnstone et al., 2005; Lence et al., 2011; Darren Lumbroso & Di Mauro, 2008)

2.1 Fundamentals of the Fate of People, Vehicles and Building

The LSM model, takes the input data of natural environment and 'People's World'. In this context, 'People's World' is representation of population at risk (PAR) along with their vehicles, buildings and other infrastructure in the selected area. In this model, two fundamental principal applies:

1. The outcome of the flood event can be understood and assessed by modelling site specific location; characteristics, behavior and movement of the Population at Risk (PAR).
2. Modelling of PAR behavior and movement may be carried out at the level of individuals, along with clear specifications of temporal and spatial distribution, personal characteristics and physical surroundings that shape their behavior, movement and their interaction between themselves and the environment.

In this work, the solver utilizes the principal of generalized event logic to determine the location of each person at each time step, to determine whether they are aware of the danger, whether they try to find the shelter to save their life or whether they would survive in the flood. With the accompanying data from depth and velocity of the flood, the receptor (people, building, vehicles) can be determined whether they could resist the impact of flood wave thus leading to the survival of the receptor in the flood. The object in the LSM have properties that vary with time. They have set of properties, such as its location at time (t), depth above which the object will float and its state (OK or DESTROYED). The Object Damage and Loss Function or ODLF is a function that determines whether and when the object changed from OK to DESTROYED with the given properties of object and time series of depth and velocity [d(t), v(t)]. Fig. 2 shows the loss function of water depth versus velocity curve to analyze the status of the receptor at each time step.

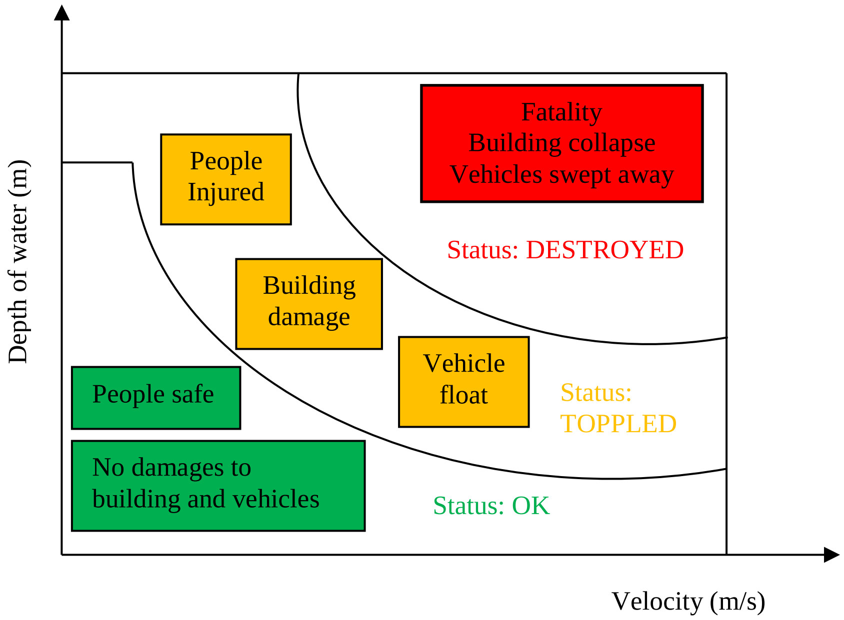

Fig. 2 - Loss function used in LSM
(Modified from (Lence et al., 2011; Darren Lumbroso & Di Mauro, 2008))

The basic hypothesis of ODLF is each object is general to have resistance (R) to withstand the loading (S) from the flood. If R<S, the OK state can change to DESTROYED. The flood wave can cause state changes for an object through toppling, instantaneous loss or cumulative loss.

The resistance R depends on the object's properties and the state of changes of the properties. A person resistance to toppling may depends on the factor such as height, weight and age. Building resistance may depend on the type of construction and the failure mechanism such as flexure and shear strength. Cumulative loss also reflects resistance reduction resulting from the exposure to the flood such as fatigue, human exhaustion or erosion of foundation. However, in the present version of LSM, they accept dv (depth x velocity) as the argument for person and building stability as practical first order approximation.

2.2 People, Building and Vehicle Interaction During Simulation

In LSM, people is the most important object in the calculation. It is termed as Population at Risk – Unit or PARU is a virtual representation of a person located in the study area. A group of PARU who shares the same location such as same building, travelling in the same vehicle or walking together is term as Population at Risk – Group (PARG). All

PARU are part of PARG even there is only one person in the group. Each PARU will move together with the PARG, will exposed to the same flood wave conditions and will attempt to escape from the flood wave together.

In order to observe the logic and the outcomes of LSM, various possible experiences or scenario may be created on the single PARU. For example, PARU is located in a building at the start of the event and not aware of the upcoming flood that may come to them. It is estimated that the impact zone (zone that will hit by the flood wave) will greatly be affected and the buildings at the PARU area will be destroyed. In order to save their life, PARU can either escaped on foot or in a vehicle. Some of the scenario examples that might happen during the event of flood wave is shown as follows:

- Scenario 1 - No Warning: The PARU is unaware of the approaching flood wave and only become aware when the flood wave was surrounding the house. PARU cannot escape and is eventually killed by the structural failure of the building.
- Scenario 2 – Warning, PARU escape by foot: PARU is warned and decides to escape on foot. Unfortunately, the wave catches and toppled the PARU, who eventually failed to resist the force from the flood wave.
- Scenario 3 – Warning, PARU escaped by vehicles: in this scenario, PARU is warned at the exact same time a Scenario 2 but decides to evacuate using vehicle. PARU was successfully reaches the safe haven.

The examples given are just a simple three scenarios that might happen for the same PARU under the similar conditions but driven into different end results. In reality, there are numerous possible scenarios that can be created under different situation of flood events may occur such as time of the day, daily activities or even the level of awareness of people. In this work, people will be considered as “deceased” when they meet one of the criteria below as follows:

- The depth of water is too high for them to walk in. This can be determined by using the parameter of highest safe depth which value is assumed about 70% of person height and the values varies according to person’s height (BC Hydro, 2006; D Lumbroso & Davison, 2018).
- The high product value of depth and velocity of flood would cause instability and lead to toppling criteria. The toppling depth is the parameter that is set to ensure that people are not drifted into the shallow water with high velocity.

When the product of depth and velocity is higher than the critical value, people who experience this condition will consider as DECEASED. In ‘People’s World’, a bulks objects of LSM could exists to interact with the flood wave which includes stationary objects such as buildings. Building in LSM includes the man-made structures such as houses, school, offices, shopping center that contain people. Outdoor location that cause people to assemble together can also be considered as ‘building’. People in the multi-story building can take refuge from flood to higher floor than attempt to evacuate through the flood water. There are three key parameters for the building to be destroyed. These conditions are either:

- The building experience a sufficiently high depth x velocity (dv) value; dv > BDVC. BDVC stands for initial critical dv for destroying building (m^2/s).
- Building experiences water depth greater than the height of the building; d > H.
- Building degrades below a defined critical level; BSS < BSSC. Building Structural State (BSS) declines below the Critical Building Structural State (BSSC) will cause the building to DESTROYED.

When building meet all the key parameter mentioned above, the building will consider to be DESTROYED and all people within the building will considered as DECEASED. Fig. 3 below shows the algorithms of building status based on the flood wave input.

Although building gives the main opportunities in term of protection to people such as safe haven, but the loss of protection in building is unavoidable. It is possible that people in the building could drown if the flood water rises over the height of the building. Thus, the model can help the affected population to make suitable decision when they are surrounded by water. Fig. 4 shows the loss protection mechanism of people in the building. Water depth is being measured at each of the floor and if the depth is higher than the height of the floor of the building, people inside the building will be considered as drowned and the building is destroyed. The multi-story building can help people to shelter inside the building rather than attempting to evacuate through the floodwater. In term of logic decision, people who are aware of the flood wave will eventually evacuate from their starting point, find the shortest route to escape and looks for suitable transport to evacuate to the safe haven. However, in some circumstance, people that evacuate could encounter the flood water with high DV and bringing them to instant loss their life (Tagg, Andrew et al., 2016). Therefore, in some situations staying in the building is the best option.

Vehicle is used by PARG for evacuation process. The distance travelled by the PARG in the vehicle is determine by using lane velocity and size of time step. The lane velocity depends on the traffic density and decreased when the density increases. The vehicle can change its state either floated or toppled by the wave based on the physical characteristics of vehicle and the dynamics of the flood. The PARG can escaped from the floating vehicle to continue of foot or being killed when the vehicle is toppling. Unlike building or people, vehicle strength does not decline with the exposure of the flood. Fig. 5 shows the image of vehicle stability in water which might be encountered by the PARG in the vehicle during evacuation. The vehicle is set to FLOATING, when the vehicle is immobilized either in the water depth and velocity is sufficient to cause the vehicle to become unstable and float. For TOPPLED situations, vehicles are set to have lost in the flood wave and considered as DESTROYED. People who are inside the vehicle will also be considered as DECEASED.

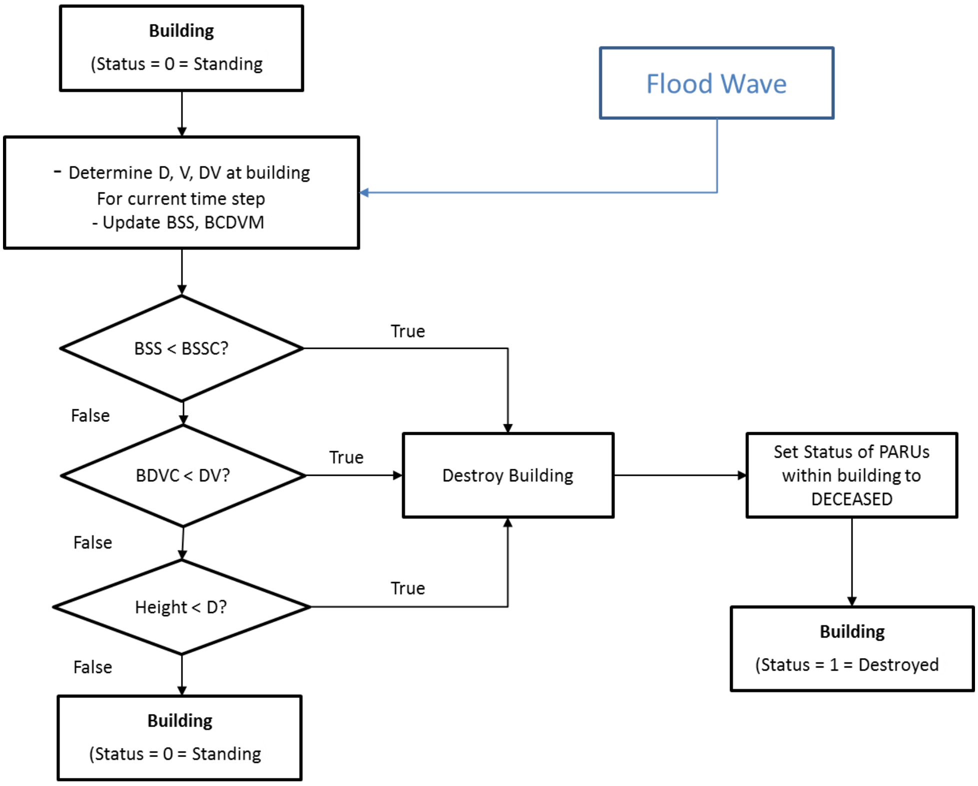

Fig. 3 - Algorithms of building structural loss (HR Wallingford, 2015)

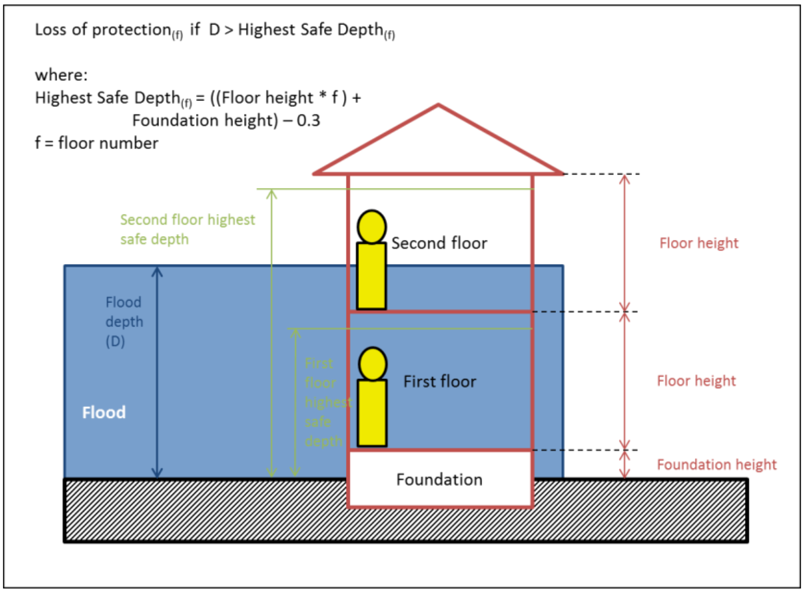

Fig. 4 - Loss protection of people in the building (HR Wallingford, 2015)

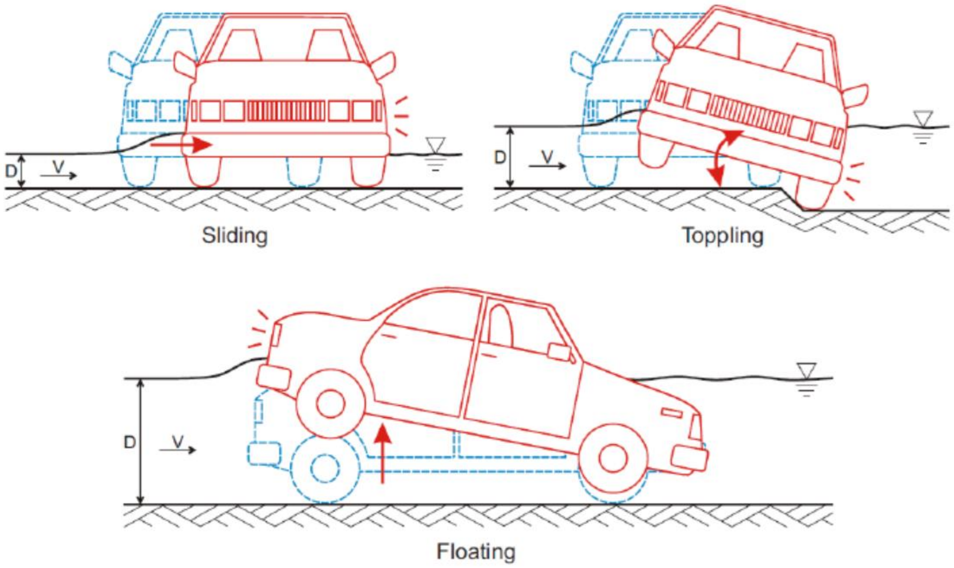

Fig. 5 - Vehicle stability in water (HR Wallingford, 2015)

2.3 Awareness and Protective Actions

In flood disaster risk management, the physical and structural approach such as designing physical barriers to reduce the damage is usually use in managing the flood risk. However, research across the world shown that the dependence on the physical approach is not fair enough to reduce the damage as it needs to follow along with the non-structural approach such as early warning system and awareness in community (Bubeck et al., 2012; Samaddar et al., 2012; Terpstra, 2011). Therefore, it is important to encourage the community to adopt the flood and disaster awareness. In LSM, individuals or people can be set to be warned by hazards which might affect the evacuation process. If there is insufficient time for PARG to evacuate, they will not able to reach the safely or if all PARG were warned simultaneously would cause road congestion which prevent an effective evacuation. PARG can be warned in several ways when the one or many methods below being applied:

- Time to First Awareness (TFAF): Each PARG is being set with a specific time to become aware. When the time assign in TFAF is elapsed, PARG will become aware. Some examples of how TFAF can applied to warn people:
    - Set a fixed TFAF for all PARG to engage simultaneous evacuation;
    - Vary TFAF randomly through their population; or
    - Assign TFAF based on spatial location to stimulate the stage evacuation.
- In the parameter file (PARAM file): there is several variables that can help to make the PARG aware. These variable is set to default values which enable the PARG to interact with each or the environment or is set to a large value to prevent any activation.
- Warning center: Warning system can set the PARG to become aware as the warning siren could trigger the individuals. When it is triggered, the warning signal would expand from the siren to the maximum radial distance to which the signal can be heard.

3. Application of LSM in Dam-Related Flooding in Malaysia

The application of LSM have been widely used around the world as the LSM characteristics itself is a micro scale which provide a comprehensive and detailed value on the issues of data collection and model assumptions. In England, the application of LSM is used in storm surge and mass evacuation (Tagg, Andrew et al., 2016) which emphasize the dedicated evacuation routes to update their evacuation procedure. Through this modelling, better understanding has been achieved related to the constrained road system and evacuation time frame. In Japan, application of LSM is used in dam break assessment which include the warning issues dissemination. From the modelling, it can show the impact of disseminating the warning issues to the surrounding.

In Malaysia, the application of LSM has not been widely used as the research on people behavior during dam breach is not of interest. However, with the recent frequent sudden flooding events in various parts of the country, awareness on the importance of flood evacuation analysis for optimization is of significant importance. In addition, changes in environmental climate around the world has triggered concerns on the safety of dams operating in Malaysia, thus its safety risk management must be relooked for opportunity for improvements. Through this research, the mitigation strategies in risk assessment can be improved.

4. LSM in Kenyir Dam and Surrounding Areas

The hydroelectric dam in Malaysia is built primarily for hydropower generations. In addition, it helps in flood mitigation, plant irrigation and water resources for domestic and industrial use. In this study, Kenyir Hydroelectric Power Station or Kenyir Dam was chosen as a research object. Kenyir Dam is located in Terengganu, the East coast of Peninsular Malaysia. It is located approximately 60 km upstream of Terengganu River Mouth and the basin have total area of 4,580km^2. A number of factors are considered for the selection of location for this work. Among others:

- The population area at the downstream needs to be evacuated fully if extreme flood occurs.
- The availability of 2D hydraulic model for this region.
- The input data such as building, people, road network and safe haven were reasonably reliable.

In this study, the effect of dam breach to downstream regions is investigated. The highly-dense populated town located 18 km downstream of Kenyir dam is modelled. Focus is given to the importance of siren and people response time to the early warning system installed at selected location in critical regions. A number of additional tools are used to assist with the preparation of input data files including ESRI ArcGIS or other GIS softwares, Microsoft Excel, Blue Kenue and text editing software.

4.1 Data Collection

4.1.1 Hydrodynamic Data

The hydrodynamic model is an important input in LSM as 2D hydrodynamic data needs to be integrated and interacted with people, vehicles and buildings which are defined based on the actual condition in the regions under study. From this hydrodynamic data, the flood characteristics such as depth, velocity, and depth x velocity with respect to time can be extracted and analyzed (Lence et al., 2011). The hydrodynamic data is obtained from MIKE-21, a 2D modelling tool for flood plain simulation and can produce the inundation maps at the downstream. The hydrodynamic module calculates the water level variations and flows in the floodplain.

4.1.2 Building, Population and Road Network Data

The study area consists different types of buildings structures including the residential houses, school, government offices, hospital, commercial and industrial buildings. The building and road network data were obtained by extraction and digitizing the information from Google Earth and Google Street view. The types of building and number of floor need to be collected and site visit were conducted for confirmation. With the assistant from ESRI ArcGIS, the coordinate of the building and road network can be obtained. Note that the coordinate in Google Earth is in form of WGS 1984 and projection changes need to be done to Kertau RSO Malaya depending on the projection of hydrodynamic data.

The population data is obtained from the Department of Statistics in Malaysia (DOSM) and the distribution of population at risk (PAR) is based on the residential houses and building properties. The total population is divided into three population age group which are 0-14 years, 15-64years and 65+ years. This information is crucial to map abilities of different people from different age group. Based on the annual report from Department of Statistics Malaysia the available percentage distribution were obtained to determine the population of the selected study (Department of Statistics Malaysia, 2019). The age group distribution is shown in Table 2.

Table 2 - Age distribution of population

Age range	Percentage
< 15 years	23.8
15 to 64 years	69.7
>65 years	6.5

This population is further divided into different group of people, PARG and people distribution according to their residential home. The people distribution at home and offices during event depends on the scenario management such as time of the day where the event occurs. For each of the houses, the number of household in that area is also obtained from DOSM (State). Fig. 6 shows the study area chosen and the impact zone if dam breach occurred. The region is centred around Terengganu River which flows downstream of Kenyir Lake. Hundreds of houses and buildings were mapped and group according to a number of villages within the vicinity. Road network is also included for the purpose of evacuation either using vehicles or on foot.

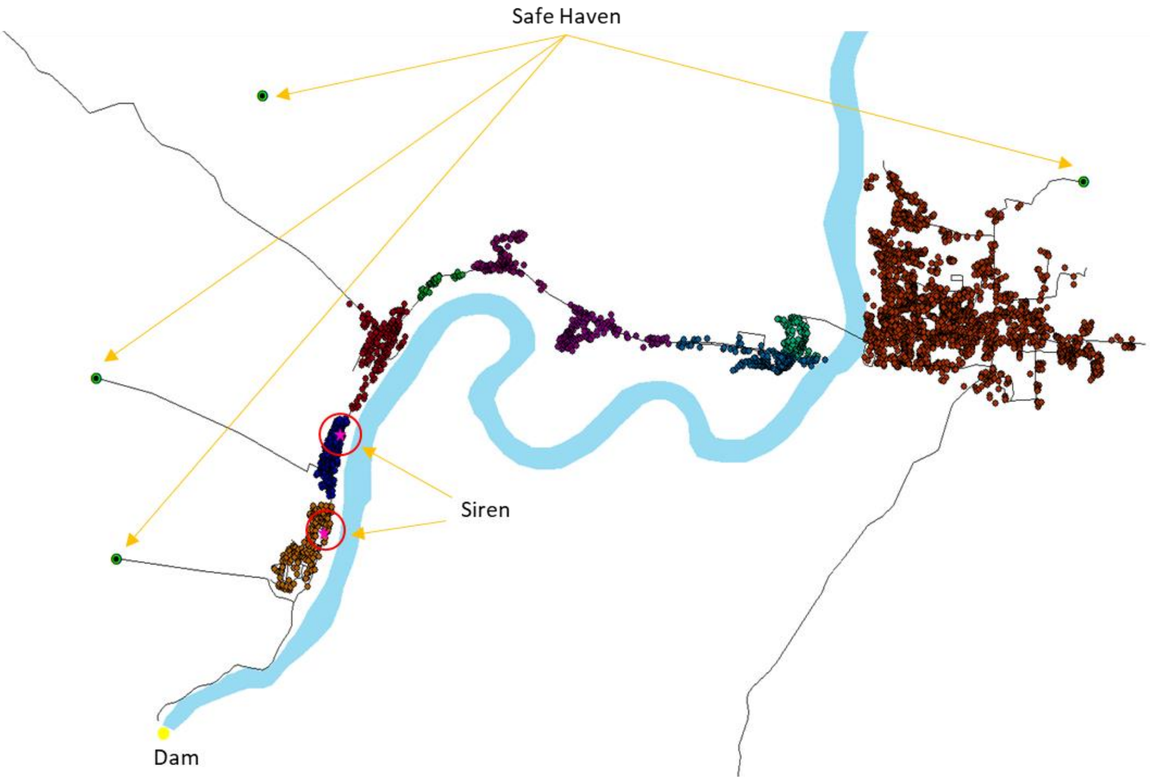

Fig. 6 - Study area

4.2 Methodology

The LSM virtual world in the study area consists of Building, Group of People (PARG), individuals (PARU), vehicle and road network which is important for evacuation route to take place to the safe haven. In this case study, LSM is set to have early warning system placed at the impact zone where it is set to disseminate warning to the downstream of the dam. Events can be described as management actions represents the potential mitigation measures in LSM (Frongia & Sechi, 2017). Events have been set for warning siren dissemination with the Probable Maximum Flood (PMF) failure conditions and the group of people have been distributed uniformly in their houses, considering that they are staying in their houses. The awareness time for PARG has been set in TFAF earlier depending on distance of the impact zone from the warning center. Prior to the simulation, the safe haven locations were pre-set based on the existing building large enough to be converted as temporary shelter for the people. However, from the hydrodynamic data simulation, it was revealed that the buildings pre-set earlier as safe haven were not suitable to be the shelter for people as the value of depth and velocity is relatively high compare to the height of building in that area. This would cause the building to collapse and eventually leads to fatality. Therefore, the safe haven locations are set at the higher elevation. Another important criterion used to determine suitable location for safe haven is the road access.

Five different scenarios were executed. The cases are divided into two main categories, one with the siren off (the case where early warning siren not available), which represent the current condition in the region and the other case is with the siren (with two locations identified for the installation of the sirens). For both cases, the effect of timing when siren is triggered (warning time) and the effect of people response delay by 10, 30 and 60 minutes (people) are also investigated. These scenarios are carried out to investigate the effect of people delay if actual disaster on flooding due to dam break happen. It is assumed that people react instantaneously to evacuate upon hearing the warning siren. Table 3 summarizes all the cases simulated. For the scenario with sirens, the location selected is in the vicinity where impact of sudden flooding are the highest. This is important to assist the authority in spreading the warning radially to people at risk in the area. The warning radius for both sirens are set at 1km based on the specification of the physical siren considered for installation. The simulation is repeated for a few times to ensure that results are consistent and reliable.

Table 3 - List of scenario for simulation

No	Scenario	
1.	Siren	No Warning (Siren off)
	People Response Time	1.1 No delay 1.2 600s delay (10 minutes) 1.3 1800s delay (30 minutes) 1.4 3600s delay (1 hour)
2.	Siren	Warning (Siren at dam breach)
	People Response Time	2.1 No delay 2.2 600s delay (10 minutes) 2.3 1800s delay (30 minutes) 2.4 3600s delay (1 hour)
3.	Siren	Warning (Siren early 1hour than dam breach)
	People Response Time	3.1 No delay 3.2 600s delay (10 minutes) 3.3 1800s delay (30 minutes) 2.4 3600s delay (1 hour)
4.	Siren	Warning (Siren early 2hour than dam breach)
	People Response Time	4.1 No delay 4.2 600s delay (10 minutes) 4.3 1800s delay (30 minutes) 4.4 3600s delay (1 hour)
5.	Siren	Warning (Siren early 4hour than dam breach)
	People Response Time	5.1 No delay 5.2 600s delay (10 minutes) 5.3 1800s delay (30 minutes) 5.4 3600s delay (1 hour)

5. Results and Discussion

There is a total of 5 cases on the effect of sirens are simulated (1 with no siren, 4 with siren and different warning time). For the case where siren is turned on, the effect of people delay in evacuation is also investigated. Fig. 7 shows an overview of a few snapshots taken in certain time intervals from the simulation results. This is taken from a complete real time simulation for all scenarios. The example given from this figure is for the case of Scenario 2 (siren triggered at the time of dam breach, 10minutes people delay). The graphical representation shows the dynamics of people response to the siren warning and water flow during the event. Fig 7a shows the overall scenario for the region at time t=0s where dam breach starts to occur. Note that siren warning starts to trigger at the exact time of dam breach. At this time, the condition is normal. Fig 7b shows the condition at t=10 minutes. When siren is triggered, people living within 1 km radius starts to evacuate after delay 10minutes from their home and move towards safe haven pre-set in certain locations in the region. In this example, 10 minutes after the siren is triggered, a number of people group can be seen moving to the safe haven (yellow dots in Fig 7b). These group of peoples are assumed to safely evacuate as water from the breached dam has not yet arrived at the location. Destroyed buildings could be identified from the figure when it changes colour from grey to black. In emergency management, building may not have any improvement as the building resistance towards depth and velocity can only be changes using their structural measures. In Fig 7c, most of the region are covered with water, indicating that water that spills as a result of dam breach, reaching the region under investigation at time, t = 4 hours, 33 minutes and 30 seconds. It is interesting to note that there are significant number of red dots that appear in densely populated areas along the road, within the vicinity of buildings These red dots indicate fatalities among the people who failed to evacuate on time. As time increases, the flooded region is getting bigger as shown in Fig 7d. It is also noted that the red and black dots increase which indicate the increases in the number of fatalities and building destroyed. At this point in time, the time is 9 hours, 56 minutes and 30 seconds.

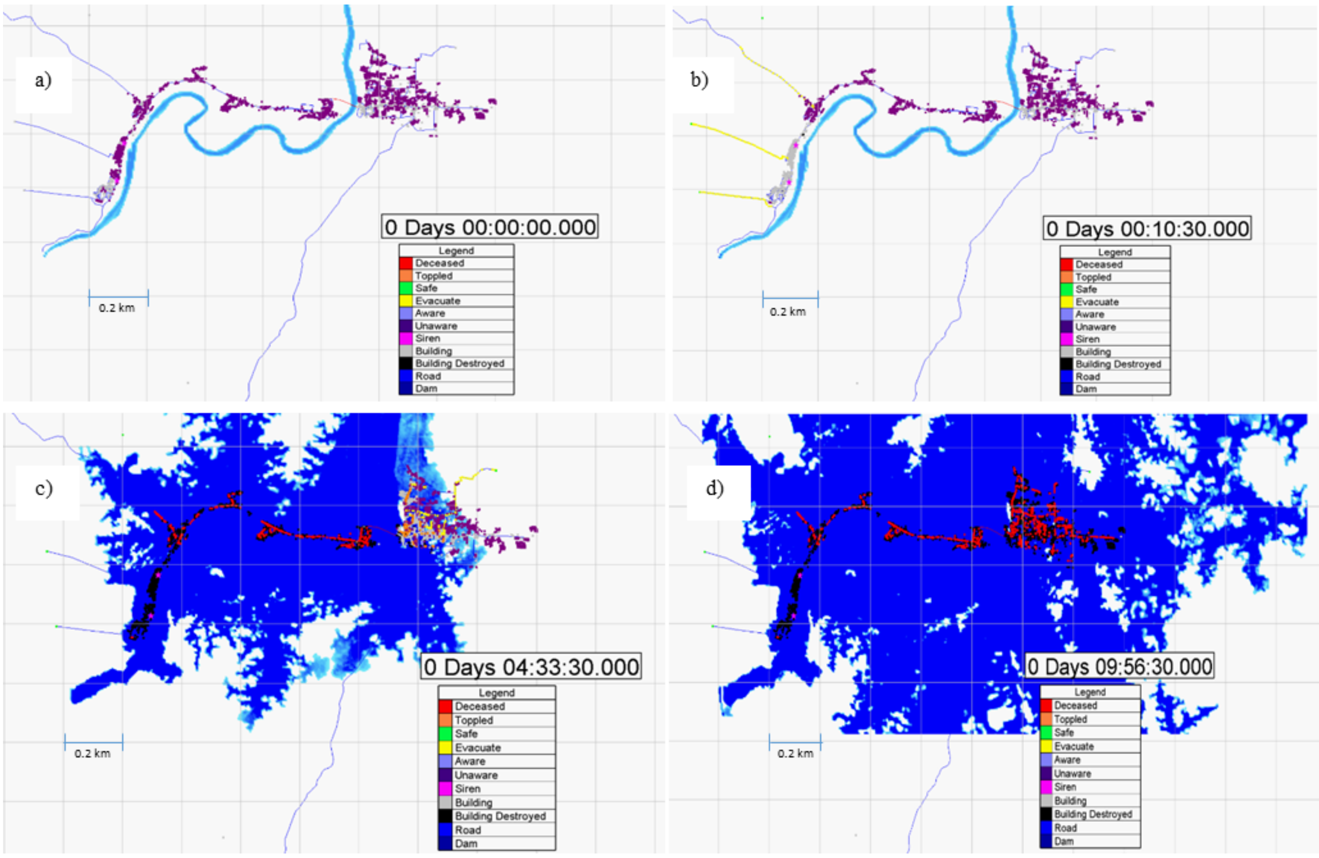

Fig. 7 - Snapshots from result for the case where siren is triggered at the time off dam breach; (a) t=0s; (b) t=10 mins 30 s; (c) t=4 days 33 mins and 30 s and; (d) t=9 days, 56mins and 30s

5.1 Effect of Warning System

From the results of all cases, it shows that the existing warning siren does help in evacuation process. In No Warning scenario, the total fatalities evaluate is very high which covers 90% of the total population at risk (PAR) in the impact zone. When the siren is activated during the dam breach, the number of fatalities slightly decrease. People are aware on the warning issued and begin to evacuate but unfortunately trap in the flood due to high velocity-depth (DV) of the flood which resulting the people at risk unit (PARU) experience drowning in the flood. A group of people at risk (PARG) and vehicles would follow the same results as PARU conditions. It was also noted that most of the building which is located in the impact zone is not able to withstand the force of velocity-depth (DV) at this parameter is found to be much higher compared to height of building. The model was later improvised by considering people delay in response time which may affect the number of fatalities during the evacuation. In reality, people will have tendency to delay their evacuation for different reason, e.g. having perception that the alert will eventually die out and situation will be back to normal, afraid of theft to their properties, taking time to secure important documents prior to evacuation and etc.

5.2 Effect of People Delay

In the next scenario, the model was run with early warning dissemination from the time where dam started to breach. People response delay were simulated for 10 minutes (600sec), 30 minutes (1800sec) and 60 minutes (3600sec). The summary of fatalities for different cases simulated in shown in Fig. 8. From the figure, the number of fatalities when there is no siren can be treated as a reference to the subsequent scenarios. In this case, the number of fatalities when there is no siren is approximately 13500. This is equivalent to 90% of the total population in the town and surrounding villages. In the case where siren is activated at the time of breach, it can be seen that the number of fatalities is greatly reduced. In this case, 8000 fatalities are predicted if people delayed their evacuation by 1 hour. In other words, the reduction in fatality when early warning system is present is approximately 41%, considering longest people response delay. If people delay can be shorten by 30 minutes, the prediction for fatalities can be reduced to 5700. The fatality rate is predicted to be further lowered when delay can be shortened to 15 minutes or 0 minutes (4100 and 3900 fatalities respectively). In the following scenarios, if the siren can be activated 1 hour before dam breach, the number of fatalities is predicted to be 3900. This is considering that people delay is by 1 hour. If the delay can be reduced to 30 minutes, 15 minutes and 0 minutes, the number of fatalities is also expected to reduce to 2200, 1800 and 1700 respectively. If the warning siren can be activated much earlier, say 2 hours before dam breach, the number of fatalities for worst delay response by 1 hour is

1200. If people delay time can be reduced lesser than 1 hour, the fatality can be reduced to zero. Any siren triggered much earlier than 2 hours, say 4 hours before dam breach results in no fatality to the community as long as their response delay is 1 hour maximum. According to (Lim et al., 2013), there are few reasons that could affect people evacuation decision such as risk awareness, knowledge on the disaster, flood warning and evacuation order. This decision may look simple, however it involves complex behavioral and external factor which may affect the number of fatalities. This analysis also shows that siren warning time is directly proportional to the number of fatalities. It is also imperative that evacuation time must be executed and disseminated earlier than the flood warning to minimize fatalities and damages. Based on the analysis on the effect of early warning system and people response delay, the siren must be activated at least 4 hours before dam breach to ensure zero fatalities in the regions provided the people response delay is limited within an hour after hearing of the warning siren. In this study, vehicle has been used as a transportation of PARG to evacuate considering the distance between impact zone and the safe haven is far away. By providing the adequate warning time for the evacuation process, PARG able to reach safe haven safely and minimize the loss along the roadside.

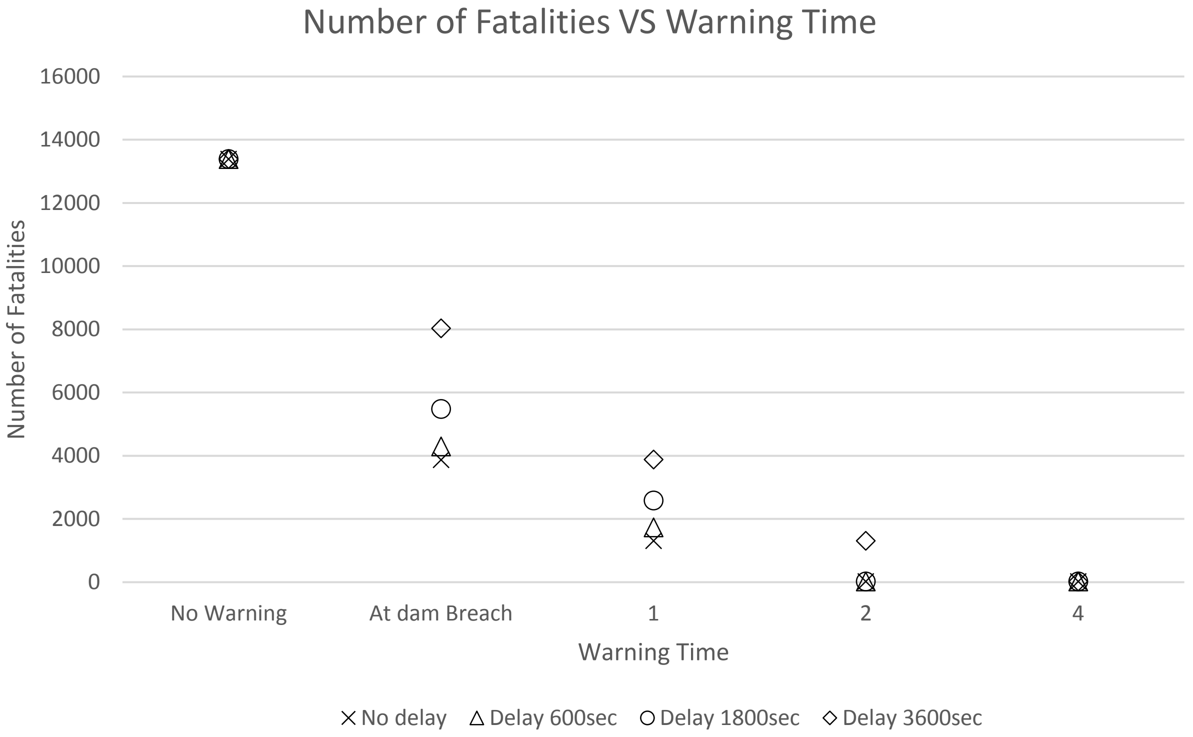

Fig. 8 - Summary results of all scenario simulation

6. Conclusion

Extreme flood event causes by dam breach poses a high risk to people and properties at downstream of the dam. An emergency management planner should consider the ‘worst case scenario’ such as PMF dam break to get a realistic conception of risk as number of fatalities is an important measure to determine the level of severity of disaster. The life safety model is one of the many tools that could provide a direct and transparent modelling of people, vehicle and building during flooding event. This research work utilize this tool to investigate potential fatality in regions closed to dam by considering many factors such as early warning system and people response delay. Based on the analysis, the following conclusions can be withdrawn:

i) Early warning system plays an important role to alert communities for evacuation during the event of disaster. For the case of flooding due to dam breach in the region under study, the early warning system is able to reduce fatality by 41% if it is triggered at the time of breach. If the siren is triggered earlier, the life that can be saved is much higher.

ii) The effect of people response delay for evacuation is as important as the early warning system. Swift response to evacuation upon hearing early warning system can reduce fatality rate significantly.

iii) The early warning system must be triggered latest 4 hour after dam breach to ensure zero fatality.

With the increasing concern in emergency plans of the dam, this work provides a method to estimate the possible loss of life. Although it is noted that for most dams, the likelihood for failure is very small, risk assessment and measure to prepare for the worst case is vital for emergency preparedness. The findings can be used as an input to the design, planning and implementation of emergency evacuation plan in the event of dam-related disaster in Malaysia, particularly in the surrounding area of Kenyir.

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