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The Risk Calculation of Hazardous Zones Created by Flammable and Explosive Chemicals, LPG Tank Example

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Abstract

The determining of hazardous areas created by flammable and explosive chemicals is important to obtain a safe working environment. Taking precautions and prevent explosions require detailed investigations and accurate calculations instead of superficial and personal experience. In this context, possible leakages and leaks occurring around the LPG tank and its connections in a real enterprise were evaluated and the border of possible explosive atmosphere areas was calculated by the ALOAH program according to the TS 60079-10-1 standard. Based on the secondary discharge of the LPG from the bottom of the tank, the discharge characteristics were calculated as 4.946578 and 3.926692 m^3/s at sonic and subsonic conditions respectively, and region radii, 10.8 m. The explosive atmosphere of the LPG tank was concluded that matched well the definition of Zone 2. The risk severity score of explosive atmospheres was calculated as 12 by using the risk assessment method of matrix system with approximations, possible in a week (3P), and the effect that could cause serious injury (4P). Serious threats and devastating effects were fictionalized clearly by explosion scenarios of the LPG tank. The calculations of explosive borders for flammable chemicals are necessary to prevent explosions, fires, and toxic effects of leaked chemicals by taking measurements on time. It is also necessary to calculate explosive areas and possible sceneries for each chemical separately for accurate results and effective control.

Key words: Flammable and explosive chemicals, ATEX, hazardous environment, LPG

1. Introduction

Explosion or burning risk occurs because of leakage of liquids or gaseous chemicals that can easily evaporate in room conditions or at higher temperatures. This usually occurs when flammable explosive materials leak or pour into the environment during transfer from containers or valves where they are contained, and then merge with the ignition source. If there is enough oxygen in the environment, the third component required for fire is a spark (fire inductor) for combustion or explosion. For a substance to burn or explode, the substance and oxygen must be mixed in a certain proportion. The percentage ratio of air and flammable substance to the total mixture is determined as the explosion limit of that substance [1,2]. Thus, the flammable material that spreads to the environment and mixes with air at appropriate rate creates an explosive atmosphere. This ratio is called the flammability limit. The flammability limit of the $CO/H_2/N_2$/air mixture compared in the presence of limited oxygen [3], the highest flammability limits of hydrocarbons diluted with inert gas [4], and the explosion behaviour of the hydrogen-enriched natural gas mixture have been investigated [5]. It is understood that the air mixture required for the explosion of each explosive chemical is different.

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The pressure formed as a result of the amount of the reactant and products may cause damage to the structures around the explosion source, collapse of the walls and cause serious material damage and even accidents that may result in death. As a result of the explosion in the Istanbul Davutpaşa industrial site in 2008, 21 people died and 117 were seriously injured, 2 people died and 2 people were injured as a result of the explosion of the epoxy resin reactor in Tuzla, Istanbul in 2011, On October 11, 2017, a large-scale explosion occurred in the Tüpraş Izmir refinery with the combination of naphtha vapor with spark, and major damage occurred [6].

An explosion occurs when gas, liquid or solid materials that mixed with oxygen in the appropriate ratio exposed to the igniter. Some of the most used gases with high explosion risk in the industry are methane, propane butane, hydrogen, acetylene, and LPG. Each of these gases has its own specific explosion mix rates with air. In addition, the flash point, which is defined as the point where the vapours of flammable substances and suitable mixtures of oxygen meet the igniter, and the ignition temperatures at which it ignites when heated without any igniter are also important factors that determine the explosion conditions. The flash and ignition temperatures of ethyl alcohol were recorded as 13.7 °C and 362.7 °C respectively [7]. Another important industrial chemical that has the potential to create explosive atmosphere because of its spread to the environment is LPG, known as liquefied petroleum gas. Dust of solid substances can also create explosive atmosphere when they form a suitable mixture with air. This situation is technically defined as explosion of powders which have ignition energy less than 25 mJ. Low humidity and high ambient temperature further reduce this energy and increase the risk of explosion. Special precautions, clothes and measures to increase ambient humidity are applied for dusts with ignition energy less than 10 mJ. An explosion occurs when electrical arcs, mechanical friction, hot surfaces and static electricity sources, which are considered as involuntary ignition sources, come into contact with oxygen mixed with flammable gas, liquid or solid at an appropriate rate.

In order to be protected from such explosive environments with effective and technical measures, the European Union directive on atmospheric explosions ATEX 95 has been put into practice. ATEX was translated into Turkish by the same name and that was included in the occupational health and safety legislation applicable in Turkey. The standard 99/92 / EC, defined as ATEX 137 or ATEX Workplace Directive, contains the minimum requirements for the protection of workers from the risks of explosive atmospheres. This directive is also basic basis for the dated 30.04.2013 and numbered 28633; "Regulation on the Protection of Employees from the Dangers of Explosive Environments". There is no precise definition of what atmospheric conditions are mentioned in this directive and related regulations. But in general terms: conditions where pressure values in the range of 0.8-1.1 bar and a mixture temperature between -20 °C and + 60 °C are provided as atmospheric conditions and these German EX-RL definitions are used as the values [8]. To be protected from the damages of explosive atmospheres, these environments should be well known. Based on the ATEX directive, atmospheres suitable for explosion are divided into zone classes in accordance with the TS 60079-10-1 standard, depending on the duration and frequency of the atmosphere with the risk of explosion. These regions are Zones 0, 1, 2 for gases and vapours as Zone 20, 21, 22 for dusts are named from the most effective and dangerous to less dangerous. The description of effectiveness for all types of explosives is from very impact to low, often explosive, occasionally, and rarely. Explosion risk should be defined to avoid explosive atmosphere and necessary precautions should be taken to protect employees from dangers arising from explosive environments. The first of these measures is to eliminate at the source, the second effective method is to prevent the spread of solid, liquid or gaseous substances that will create an explosive atmosphere. Leaks arising from inlet and outlet valves, connections, pumps, and other equipment, where easily evaporative liquids and gaseous substances in room conditions mix into the ambient air from the containers where they are stored, should be controlled, and eliminated. Creating an adequate and effective ventilation system to dilute the amount of substance in the environment is the most important control method after removal at source. Thus, the flammable explosive substance can be prevented from reaching the explosion limit. Scenarios and countermeasures for any explosion situation should be developed with the calculations to be made considering the shape of the leakage places, leakage time, type of leakage and chemical properties and the employees should be protected from explosive atmosphere hazards. In this study, the possible explosive atmosphere limits around the LPG tank used in a real enterprise were determined using the ALOHA program. Taking these calculations into consideration, risk assessment and recommendations are specified to protect employees from possible explosion risks. It is important to use advanced technological programs and materials within integrated disaster prevention program to determine occupational threats more successfully for not only industrial but also natural disasters such as flow and earthquake [9,10].

2. Material and Method

In this study, the determination of the points released from the LPG tank in an enterprise operating in the chemical field and having the potential to create explosive atmosphere was calculated using the ALOHA program according to the TS 60079-10-1 standard. The hazardous area is defined by determining the impact area of LPG released from the tank bottom and from the pump flanges. Necessary measures and suggestions have been determined according to the risk assessment made using these calculation values.

For this, the following equations specified in the TS 60079-10-1 standard prepared by IEC (International Electrotechnical Commission) and translated into Turkish by TSE will be used. The zone qualifications and distances of the leaking chemical specified in the regulation, the spread areas, and characteristics of the explosion as a result of the possible explosion will be calculated using the ALOHA modelling program. Considering the numerical data to be obtained, the probability of dangerous situations that may occur as a result of leakage and the damages that may be caused by these dangerous situations will be made according to the L-type risk assessment matrix, precautions and equipment will be specified. The discharge rate (W) of the chemical that creates the risk of explosion from the container is calculated according to the equation given in Table 1.

Table1. Chemical discharge rate (W_g) equation, kg / s

Equation	Parameter	Unit	Explanation
$W_g = C_d S \sqrt{2\rho \Delta P}$	W_g	Kg/s	Discharge rate
	C_d	-	Discharge coefficient
	S	m^2	Discharge area
	ρ	Kg/m^3	Liquid density
	ΔP	Pa	Pressure difference at discharge area

The chemical's discharge characteristic (DC) calculation was made using the equation in Table 2 by using the discharge rate to occur from the leakage cross section per second.

Table 2. Discharge characteristic (DC) of the chemical, m^3/h

Equation	Parameter	Unit	Explanation
Discharge Characteristic $=\frac{W_g}{\rho_g * k * LFL}$	DC	m^3/s	Discharge characteristic
	W_g	Kg/s	Discharge rate
	k	-	Safety coefficient
	ρ	Kg/m^3	Vapor density
	LFL	Vol/vol	Lower flammability limit

W_g and DC values are used to determine the degree of dilution (DDL). The area where the point where these two values intersect is on the graph of the ventilation velocity against the bleeding characteristic gives the degree of dilution. The probable size of the leak in the area where the leak occurred can be determined if the type of leak is known from the drain characteristic versus distance graph.

In order to determine the air flow velocity, the properties of the chemical substance and the open or closed, i.e. air inlet and outlet feature of the environment should be considered. Considering these and other necessary parameters, the calculator finds the most appropriate ventilation value from the ventilation and zone (ZONE) type table given according to EN 60079 -10-1 standard and uses it in the necessary calculations (Table 3). In this study, the ventilation velocity was evaluated as 0.5 m/s by evaluating the ambient conditions.

Table 3. Ventilation speed chart

Open space types	Barrier-free sections			Blocked sections		
High from ground level	≤2 m	≥2 <5	>5m	≤2 m	≥2 <5	>5m
Estimated air flow rates to reduce light gas or vapor releases from the molecular mass of the air (m/s)	0.5	1	2	0.5	0.5	1
Estimated air flow rates to reduce heavy gas or vapor emissions from the molecular mass of the air (m/s)	0.3	0.6	1	0.15	0.3	1
Required air flow velocity to vent the evaporating amount of liquid accumulated pool at random height level (m/s)		>0.25			>0.1	

*For closed areas, 0.5 m/s ventilation speed value is generally accepted. There must be special circumstances in order to accept different values (eg points where air inlet and outlet are provided). The mechanism used for ventilation should be controllable and the minimum air flow rate should be calculated.

3. Results

It has been determined by expert examinations that the LPG tank subject to the study has two types of flange connections, one is in the pump line and the other is under the tank. The parts of these flanges that leak or are suitable for LPG leakage were examined and dangerous areas were determined in case of possible leakage. The representation and calculated distribution distances of the chemical leakage caused by the tank in case of possible leakage are given in Figure 1.

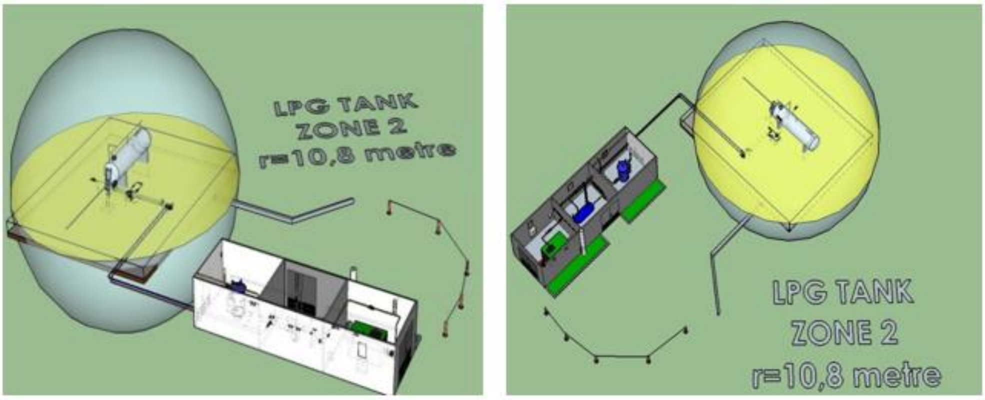


Figure 1. Representation of the zone which the LPG leakage is dispersed from different perspectives

3.1 Classification of dangerous area

The classification of the hazardous area has been decided considering the discharge characteristics in the ventilation efficiency table (Table 4). It has been concluded that both leakage environments comply with the definition of danger known as Zone 2, which is defined as "places where explosive atmosphere created by air mixtures of flammable substances in the form of gas, vapor and fog may occur occasionally under normal operating conditions". In Table 4, the points where the information on the dilution degree and the discharge pattern intersect give the class of the danger zone. The discharge source refers to the area where the flammable chemical leaks into the environment, causing an explosive atmosphere. The discharge type of the chemical is classified into three groups according to the leakage state and the leakage time. In this study, the area shown in yellow represents the area where the leak is [9,11,12].

a) Continuous discharge source: Situations in which the discharge occurs continuously for a long time or for a short time and frequently,
b) Main discharge source: Situations where discharge occurs at regular intervals or occasionally under normal process conditions,
c) Secondary discharge source: Covers situations where discharge is not expected to occur under normal process conditions but can occur sparsely and for a short time.

In our study, it was decided that the leaks in the LPG tank were generally in the form of secondary discharge, considering that they occur during the loading or delivery of LPG to the system. Since the LPG shipment is made automatically from the main control desk, the valves under the tank normally remain closed. Material passes through both upper and lower flanges during shipment and there is a possibility of leakage. The type of leakage plays an important role in the most accurate calculation of the explosion probability.

Table 4. Ventilation efficiency table

Discharge Degree	**Ventilation Efficiency**						
	High Dilution			**Medium Dilution**			**Low Dilution**
	Reliability Degree						
	Well	Average	Low	Well	Average	Low	Well, Average or Low
Continuous discharge	Safe (Zone 0 Ne)[a]	Zone2 (Zone 0 Ne)[a]	Zone1 (Zone 0 Ne)[a]	Zone 0	Zone 0+ Zone 2	Zone 0+ Zone 1	Zone 2
Main discharge	Safe (Zone 1 Ne)[a]	Zone 2 (Zone 1 Ne)[a]	Zone 2 (Zone 1 Ne)[a]	Zone 1	Zone 1+ Zone 2	Zone 1+ Zone 2	Zone 0+ Zone 1[c]
Secondary discharge [b]	Safe (Zone 2 Ne)[a]	Safe (Zone 2 Ne)[a]	Zone 2	Zone 2	Zone 2	Zone 2	Zone 0+ Zone 1[c]

Note: "+" means at around the mentioned area.
a: Zone 0 Ne, Zone 1 Ne and Zone 2 Ne Refers to theoretical regions with negligible dispersion limit under normal conditions
b: The Zone 2 area created by the secondary discharge may exceed the area attributable to major or continuous discharge degrees. In this case, the larger distance should be used.
c: Zone 0 is used if, in practice, the ventilation is too weak, and the dispersion is such that there is a continuous gas environment (almost no ventilation).

The degree of dilution can be defined as the effectiveness of the discharge from a source to become safe from explosion and/or fire by mixing with air. Reducing the amount of chemicals discharged with artificial or natural ventilation to below the explosive value is a measure of neutralizing the source of danger in the environment. With high dilution, the amount of chemical around the discharge source rapidly decreases and almost no persistence after the discharge stops. Medium dilution: While the discharge continues, the chemical amount is taken under control by creating a stable zone limit value and the explosive gas environment is not permanent at a high level after the discharge is completed. Low dilution: Concentration is large while discharge is in progress and/or expressed as persistence of flammable environment after discharge is complete [13–15]. In our study, the dilution degree of both pump and bottom flanges was found to be "medium dilution" Figure 2. This indicates that the amount of LPG leaking into the environment is higher or equal than the value swept by air, so there is a danger of explosion or burning in medium ratio. The degree of dilution is included in the standards as the area where the values intersect in the chemical's discharge characteristic graph against the air flow velocity in the environment where the discharge source is located (the air flow velocity of the LPG source discussed in this study was determined as 0.5 m/s using Table 4) [6].

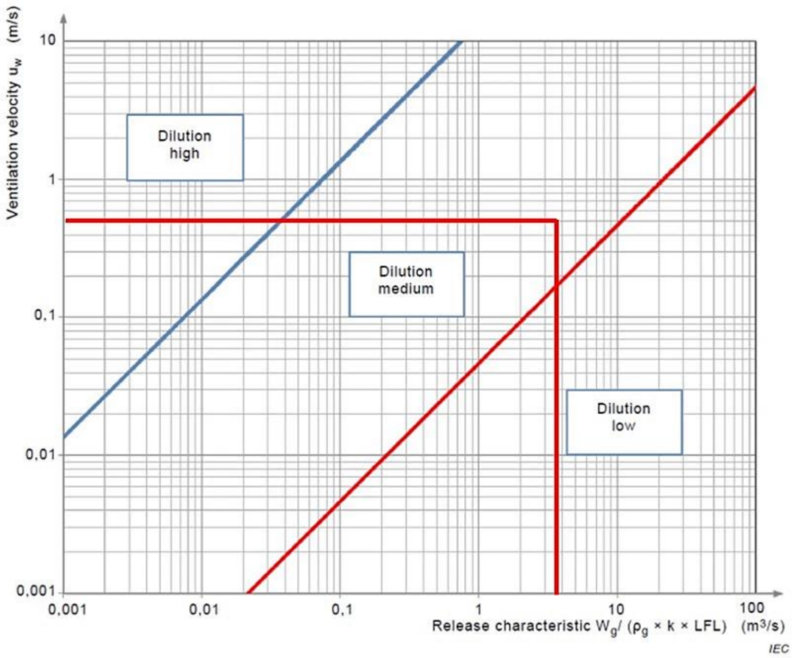


Figure 2. Air flow velocity-discharge characteristic graph used for dilution degree calculation

The discharge characteristic is one of the important data used to obtain basic values on the rate of spreading of gas or dust that can leak from a point to create an explosive atmosphere and danger zones [9]. The three definitions used in explaining the characteristics of the discharge are jet, diffusion, and heavy gas types. The discharge characteristics of the LPG tank was calculated as 3.926692 m^3/s and 4,946578 at sonic and subsonic discharge conditions respectively. Jet Type Release: It is the discharge of a chemical from a leak with high pressure and high speed. In time, the jet emission dilutes and loses its effect without air flow. Diffusion Type Discharge: It is the release that disperses with low-speed diffusion or loses its separation momentum by hitting the surfaces it spreads. Heavy Gas Type Emission: These are heavy gas or vapor emissions that are distributed in the direction of horizontal surfaces [16].

In our study, it was evaluated that the emission from the LPG tank was heavy gas in both the upper and lower flanges, and it was used to calculate the emission distance. Heavy gas emission means the low exit of gas or dust, and its impact area is further than diffusion and jet type dispersion. As can be understood from its definition, the impact area heavy gas type emission is high, and the explosive ambient distance is high possibility due to lower dilution.

3.2. Calculation of zone radii

The calculation of the zone radii is made by determining the hazardous distances (m) corresponding to the discharge characteristic value on the line showing the emission type in the graph of the discharge characteristic versus the hazard distances. Accordingly, it is seen that the radius of the dangerous area formed by the line flanges is 10.8 m Figure 3. Other features and evaluation results regarding the discharge points formed from the LPG tank are given in Table 5. Danger zones were characterized by numerical values in the calculations made using TS 60079 standard data and graphics. This study offers a scientifically based detection opportunity instead of determining the danger limits of explosive gas and dust substances with qualitative observations and experiences. Thus, more planned studies can be done to prevent dangerous situations from occurring. Success will increase in protecting employees from hazards.

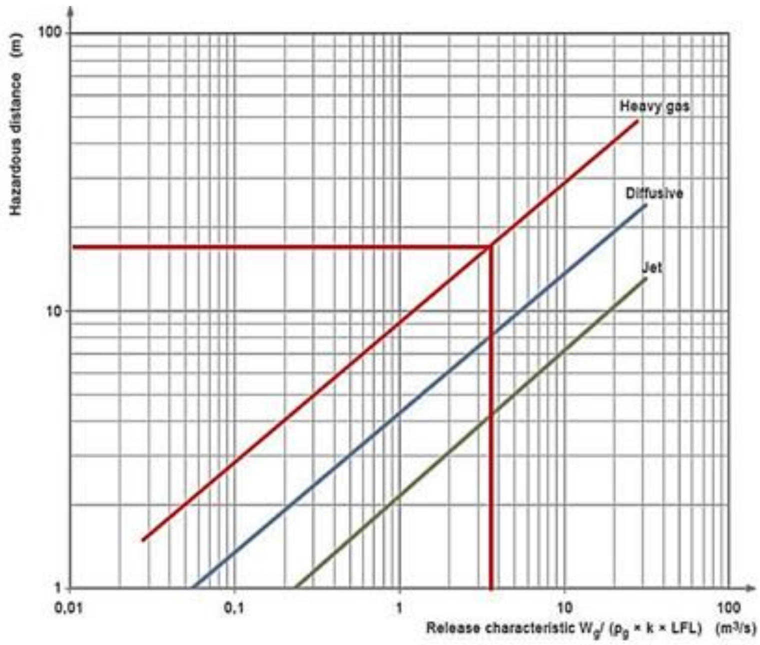


Figure 3. Emission type-discharge characteristic graph used for hazardous area distance calculation

Table 5. Features of LPG tank distribution

Properties	Unit	Value	Sonic/Subsonic
Molecular Weight-MW	Kg/kmol	53.9000000	Sonic
Leak surface area-S	m^2	0.0001000	W_g – discharge rate at sonic conditions (kg/s)
Lower explosion limit-LELm	Kg/m^3	0.082370138	
Lower explosion limit-LELv	%	2.0000	W_g – discharge rate at sonic conditions (kg/s)
Safety coefficient-k	(0.5-1)	0.5	0.103764
Universal gas constant-R	J/kmol.K	8314.0000	Rc-Sonic discharge characteristic (m^3/s)
Inner Pressure-P	Pa	600000.0	3.926692
Air Pressure-P_{air}	Pa	101.325	Rc-Sonic discharge characteristic (m^3/s)
Density of enlarged gas-ρ	Kg/m^3	2.0977	4.946578
Temperature-T	°C	40.0	Dilution degree
Air Temperature-T_{air}	K	313.15	Medium dilution
Discharge area coefficient-C_d		0.75	Zone Radius at subsonic conditions
Air flow velocity	m/s	0.50	10.8

One of the things to be considered in these calculations is that the calculation effect of the parameters is large. Many values such as discharge characteristic, degree of dilution, hazardous area distances are calculated using numerical formulas. However, in some determinations, it is understood that the use of values based on approximation and observation is also necessary. The ventilation rate should be selected using the table, the determination of the source of discharge (secondary, main, and continuous) and its shape (jet, diffusion and heavy gas) should generally be done through qualitative observation.

This makes relative evaluations necessary and thus different results are obtained from the calculations made by different people. Studies are underway that may allow more detailed calculations on explosion zones. Miranda T. J. et al. Compared the UNE 60079/10/1 standard method with computed fluid dynamics (BAD) methods in the calculation of the zones and risks of explosive atmospheres and concluded that the BAD method is more advantageous than the standard 60079/10/1 method [8]. They stated that the advantage of the method was that it allowed the calculation of the volume of the potentially explosive atmosphere. Ferrero et al. Reported the effect of an important factor causing explosion in their studies on the explosion temperature of tetrafluoroethylene gas in the reactor environment [17]. It should be considered that as the firing temperature decreases as the pressure of tetrafluoroethylene increases and this fact should also be taken into account when working with other explosive flammable chemicals. In another study, it was carried out that the structure of the molecules and the functional chemical groups attached to the molecules can change the ignition temperature [18]. In the study, the evaporation, and the changing flaming behaviors of some amine groups according to their functional molecular structures have been investigated using the methods suggested by Rowley and Wilding. The derivation of “FP ¼ 207: 2 + 23: 43nC - 7: 363nH + 49: 41nN + 64: 79IP-62: 96DP” has been proposed. Taking into account the increased IP and reduced DP factors in this derivation and the C, H, N numbers in the additional groups in the molecule, the correct result was found without deviating 137 K from the calculated flammability degree.

3.3 Potential hazard scenarios as a result of LPG tank explosion - potential explosion severity

Different reason could cause an explosion or firing of a leaking chemical. External factors, earthquakes, material defects and others indirectly may result in leakage and fire after meet sparking source when the air-fuel mixture is flammable combinations. The leak substance has two main threats: it may threat the alive which breathe the toxic vapor and fire or explosion. It was described how the leak from fuel tank may disperse and result in a fire or explosion in Figure 4.

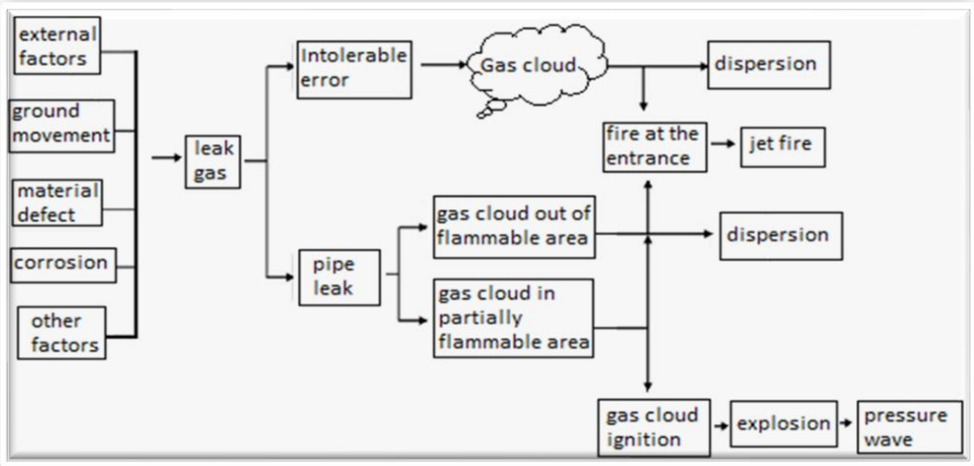


Figure 4. LPG Tank Hazard route

When evaluating the results obtained from the ALOHA program, attention should be paid to concentration irregularities, especially at very low wind speeds, very stable atmospheric conditions, wind direction changes and sloping terrain, and near the source of the leak. In the

ALOHA program, the effects of chemical reactions, particles, chemical mixtures, and land factors are not taken into account. In addition, the ALOHA program is not used in chemical dispersions that are effective at distances greater than 10 km, causing cloud formation, and chemical dispersions lasting over an hour.

In the program, the risk of the tank environment during a fire is determined by the level of thermal radiation emitted, and these danger zones are expressed in three different colours: red, orange, and yellow. The most dangerous area is the red, the least dangerous is the yellow zone. The red danger zone is the area where the thermal radiation is over 10 kW/m^2 and that results in death after 60 seconds of exposure. Thermal radiation in the orange hazard zone is between 5-10 kW/m^2, and 60 seconds exposure poses a risk of secondary burns. In the yellow danger zone where the thermal radiation is between 2-5 kW/m^2, there is a risk of burns within 60 seconds Figures 5-9. Chemical properties were given in Table 6.

Table 6. Information about the tank

Location :Gebze Kocaeli *Date : 15.01.2019* *Lower explosion limit (LEL) : 16000 ppm* *Upper explosion limit (UEL) : 84000 ppm* *Chemical mass inside tank : 22.286 Kg*	Boiling point : -1.1 ° C Vapor pressure :>1 atm Wing : 4 m/s (open area) Air temperature : 8 °C Tank Radius : 2.49 m Tank length : 10.3 m Tank Volume : 5000 L Tank fill rate : %80

3.4 Modeling of flammable liquid vapours spreading to atmosphere in case of possible leakage from LPG tank or flanges

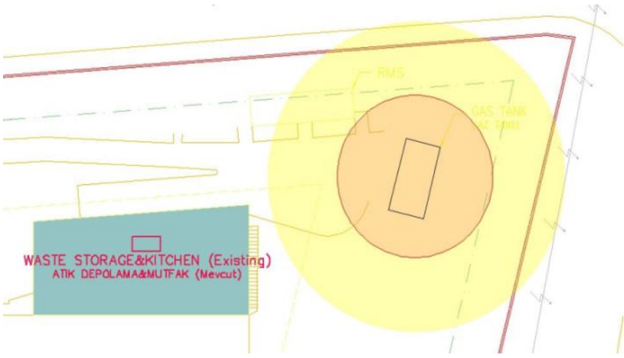


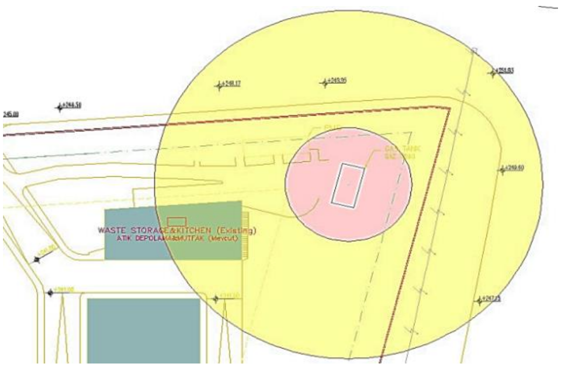
Figure 5. Toxic vapor cloud hazardous area

Toxic vapor cloud hazardous area,

Red: 11 m – (53000 ppm = AEGL-3 (60 min.)

Orange: 11 m – (17000 ppm = AEGL-2 (60 min.)

Yellow: 21 m – (5500 ppm = AEGL-1 (60 min.)



Flammable vapor cloud hazardous area,

Red: 14 m (9600 ppm = % 60 LEL = Flame pocket)

Yellow: 43 m (1600 ppm = % 10)

Figure 6. Flammable vapor cloud hazardous area illustration

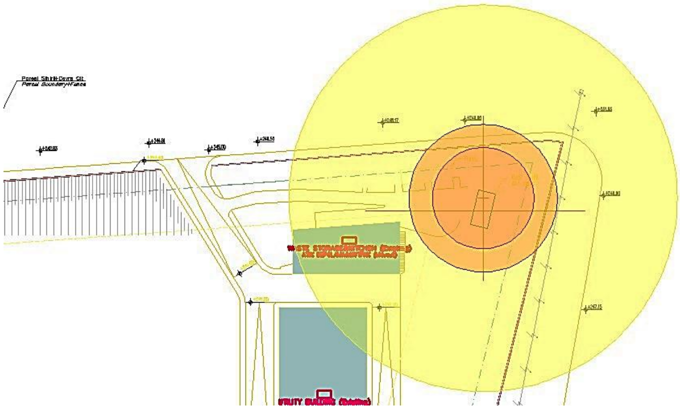


Figure 7. Vapor Cloud Explosion Zone

The explosion area of the vapor cloud,

Red Zone: greater than 0.5 bar (collapse of structures),

r = 55 meters

Orange Zone: greater than 0.2 bar (probability of serious injury), r = 20 meters

Yellow Zone: greater than 2.5 bar (shattering of glass),

r = 15 meters

3.5 Modeling of combustion of flammable liquid vapor like jet fire in case of possible leakage from LPG tank or flanges

3.5.1 Dangerous area of thermal radiation

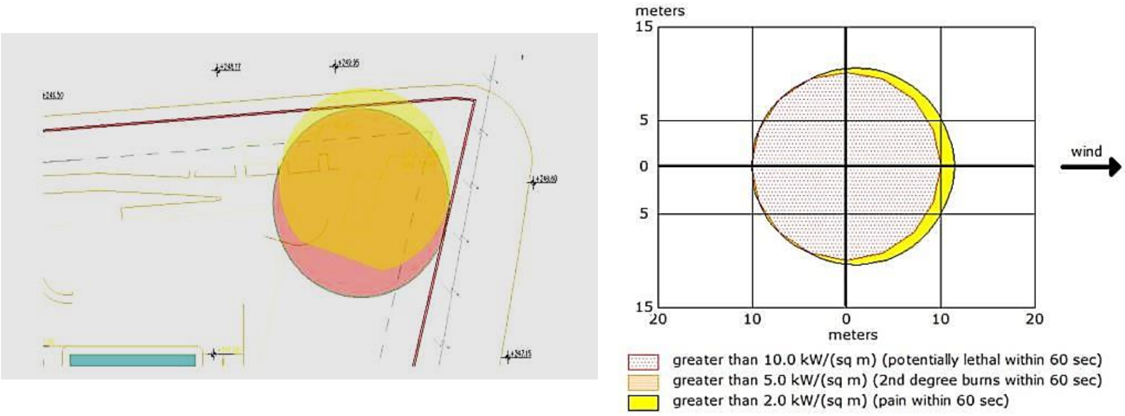


Figure 8. Thermal Radiation Zone

Conclusion/Comment: In Jet fire fires, it has been observed that the workers in an area of 10 m have a risk of death.

3.5.2 Dangerous area modeling when the tank explodes like a fireball

In this study, it is assumed that in the event of a possible leak, the second (Jet fire) and third (BLEVE) scenarios will occur. Calculations for both selected scenarios were made separately, and the results were modelled separately using the experimental design method. BLEVE explosion is a rare occurrence that only occurs when the internal pressure of the tank has increased too much, and the drain openings of the tank cannot relieve the increased pressure. This situation usually occurs when the tank heats itself after a "Jet fire" type fire that starts with a leak from the tank, or a fire in another nearby tank heats that tank by radiating and convection. For this reason, in this study, it is assumed that the combustion reaction will occur (Jet fire) primarily at the leakage point.

3.5.3 Dangerous area of thermal radiation

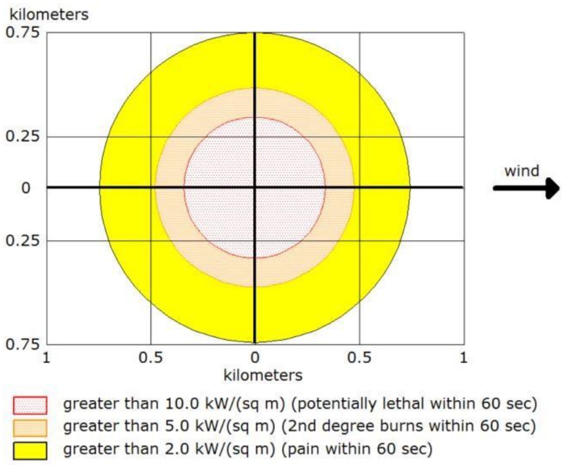


Figure 9. Thermal Radiation Hazardous Area

It has been calculated that a fatal zone may occur in an area of 300 m as a result of the expected BLEVE explosion in case of leakage of a 50 m^3 LPG tank and no intervention after the jet fire.

4. Discussion

The data obtained from the calculations showed the existence of Zone 2 where explosion may occur in case of LPG leakage. Risk value calculated in simple 5x5 matrix is calculated as 12 Table 7. The risk situation has been tried to be determined by using many approximate values and relative approaches both in risk score calculations and in calculations of the previous region and gas dispersion diameter.

Table 7. Risk assessment and measures to be taken

Flammable substance	**LPG**		**Radius of Dangerous Area**	**10.8 m**
Equipment	EX II 3G IIB T2		**Category of Danger Zone**	Zone 2
Source of discharge:	Leakage from flanges		**People to be Affected:**	All employees
Risk Assessment	**possibility**	**severity**	**Score**	
Matrix	3	4	12	

Since some of these approximations are based on the experience of the technical staff performing the calculation, it is possible that the margin of error is high in the approximation of the less experienced people. For this reason, it is necessary to precisely determine and implement the measures to be taken, considering the risk score.

In the calculations made according to the standards, the area of 10.8 meters was calculated as the danger zone during filling and in case of leakage from the flanges. The equipment to be used in this area must be EX II 3G IIB T2 non-sparking (exproof) materials. Storage within this area should be prohibited. The choice of exproof gas alarm detector used in the LPG station is a suitable and industrial type gas detector. It is necessary to try to get an idea about the corrosion dimensions by making a non-destructive examination on the pipes. Corrosion measurements are also an important test in determining the maintenance periods of the entire facility.

The clothes of the personnel who will work in the hazardous area should be 100% cotton, i.e. ESD. Work Shoes should also have ESD feature ($<3.5 X10^7$ ohms). It must be determined whether the LPG system is in the lightning rod protection area. The usage, maintenance and repair instructions of all electrical devices used in this environment should be created and kept in the relevant area. No work that could cause sparking should be done in the hazardous area and Explosive atmosphere "EX" sign should be hung in this area.

Employees should be taught what to do in emergencies (fire, glare, explosion, etc.). If any work is to be carried out around the dangerous area, the 'work permit system' should be implemented and the employees should be inspected at certain intervals. In this area, no tools other than Ex-proof hand tools and work equipment should be used. Hand tools with these features should be purchased for the maintenance team.

All electrical equipment to be used in the Explosive Environment must be of ex-proof standards (EX II 3G IIC T6). Grounding measurements should be made in annual periods and the measured values should be below 10^6 Ohm for static electricity, reports should be prepared annually and kept in the relevant file.

Limit pressure values of manometers must be marked in red line. Lightning Protection System (LPS) must be connected to the grounding system with the equipotential busbar system. When a change is made in a building or its installation, it should be checked whether the existing LPS is still maintained in accordance with this Regulation. If a nonconformity is detected during the inspection, necessary corrections should be made immediately.

Lightning rod system Inspection and maintenance programs should be defined by the LPS designer or installer with the participation of the building owner (s) or their authorized person or his appointed representative. The maintenance program should be described in detail and the maintenance programs should be carried out without delay. If we take into account that the minimum ignition energy of 75% butane is 0.25 mJ, it should not be filled at speeds higher than 1m/s.

A certificate of conformity for ATEX requirements of the tank to be filled should be provided and the wall thickness of the tank should be checked by periodic corrosion controls. There should be at least 2 wheeled fire extinguishers of 30 kg right next to the LPG Station. Fire extinguishers to be placed next to the tanks should be in a place that is hung from the wire mesh and easily accessible, except for the wire mesh (TS 862-1 EN 3-1).

Liquid flow directions should be marked with arrows on pipes that are exposed above ground. There must be a distance of at least 7.5 m between the vehicle fuelling the tank and any above ground tank.

To prevent overfilling, there should be alerts that will give an audible alarm when the liquid level in the tank reaches 90% of the tank capacity and automatically stop the liquid transfer when the liquid level reaches 80% of the tank capacity. These beepers should never affect normal or emergency ventilation.

It is required to be in the mechanism that known as the "dead man button" to the tanks, allowing the gas flow by keeping it pressed continuously and stopping the filling if not pressed should be used to prevent the transfer when operator leaves from the filling area during the transfer.

Warning signs such as "LPG", "No Smoking", "Approach with Fire", "Flammable and Flammable Substance", "No Other Authorized Person", "Turn Off Cell Phone" should be placed in easily visible places in the LPG storage area and LPG storage tank filling area.

In accordance with the Regulation on the Protection of Employees from the Dangers of Explosive Atmospheres, employees must be given explosion protection training. Necessary measures should be taken regarding grounding. It was observed that there was an equipotential grounding system in the study area, but not enough point measurements were made. Grounding should be reported according to the results of the measurements made from each point and it should be clearly stated which type of electrical grounding. Safety instructions and the issues that employees must comply with should be reported. Zone 1: Considering the zone calculations according to the CE certified ATEX, suitable electrical devices should be used for the LPG filling tanker or tank in an area of 2.5 meters. It should be kept in mind that occupational accidents include all unwanted situations such as death, severe injury, injury that have the potential to harm people and workplace devices and machines.

5. Conclusion

It is an important step in preventing hazards to know the extent of hazardous environments that are frequently used in industrial areas and will form explosive atmospheres by leaking into the environment and mixing with air in certain proportions. In this study, LPG leakage calculations that can create explosive atmosphere within the scope of TSE EN 60079-1 standard have been made. The hazardous areas around the LPG tank, the distances of these areas and the zone classification have been determined. Taking these calculations into account, the measures to be taken and the protective equipment to be used can be as follows:

Chemical leakage can damage the environment and living with the toxic, flammable, explosion and, thermal radiation effect mainly. In case of any kind of damages, the effective areas of chemicals were found to cover a large area changing from 10 to 300 m.

Calculations of explosive atmospheres in industrial facilities will give more accurate results in hazard identification. An effective risk assessment and explosion protection can be done by precisely determining the distances of explosive atmospheres in the workplace.

Burning/explosions caused by the contact of dangerous chemicals with oxygen and spark can cause fatal, serious injury or serious damage accidents. Care should be taken to select the electrical and sparking equipment to be used in the production process or in the warehouse in the ex-proof category. Since such calculations are dependent on many variables such as the type, volume, connections of the chemical in the workplace, the ventilation conditions of the environment and the condition of the leakage, it has been understood that the result can be reached for each enterprise with calculations specific to that environment.

Thanks to these calculations, it was concluded that less costly ex-proof equipment can be used instead of high-cost ex-proof electrical equipment that must be used at any time. In order to prevent possible liquid-gas ATEX explosions in order to prevent the spread of fire, explosion-proof sections in the form of block concrete and separate buildings should be created in the warehouses.

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Author Contributions

All authors contributed to the study conception and design. Material preparation and data collection was performed by Omer Ahmet Uslu, analysis and interpretations were performed by Dr. Huseyin Gumus and Dr. Bulent Buyukkidan. The first draft of the manuscript was written by Dr. Huseyin Gumus and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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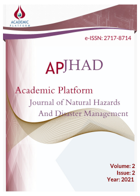

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How Social Networks have become the "Panacea" or "Protective Firepower" of Flood Victims: A case of community flood disaster management in Sri Lanka

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Abstract

Social support networks have been become one of the mostly influential metaphors in many areas around the world, especially in terms of mitigating disaster consequences and revivifying disaster affected livelihoods. More importantly, reciprocal supports ties are more powerful in healing disaster wounds of communities. Especially social capital legacies enrich by reciprocal support networks by the ways in which making may hopes among disaster victims. In this context, the objective of this study is to investigate the social support network behaviors in supporting 16 flood-affected households in the mass flooding event occurred in 2017. Particularly, the study researched social support network behaviors at different flood inundation phases such as before, during, and after. This study collected primary data (mainly social network data) using household survey and filed observations. The study used the Social Network Analysis (SNA) method for the network data analysis. This article shows that flood affected households have received social network supports in different magnitudes at before, during, and after flood inundation phases. More importantly, provision of foods, water and basic needs, sheltering, clearing contaminated households, and emotional supports have mobilized and reciprocated among victims in reviving their livelihoods. The social support network legacies have evolved at different flood inundation phases. This study fills the gabs in the flood disaster discourse on Sri Lankan context.

Key words: Sri Lankan floods, Social support networks, resource mobilization, evolution of support networks.

1. Introduction

Natural disasters have dramatically been escalating not only in the global north, but also throughout the global south as well. Especially meteorological disasters such as severe floods, cyclones, and drought (e.g. wildfire or forest flyer because of the heatwaves) have come to the fore [1-4]. The main reason behind these escalating natural calamities is the adverse climatic change that has been experienced everywhere in the world [5-6]. Especially, Turkey, Germany, and USA have been experienced torrential rains and sudden flash floods very recently triggering gigantic consequences/damages to human lives and property [7-9]. Particularly, recording rain falls in first time on the peak of Greenland was an unexpected event. Scientists say that this is a very stark sign of future climate crisis [9]. This special natural event implies that the global temperature has adversely been rising. This circumstance accounts for the rapid melting of Ice caps and definite sea level rise. The IPCC warns that these tipping points drive towards a range of catastrophic disaster events around the world. In contrast, according to the recently revealed information, more than 200 international "health journal" have been urged world leaders that the needfulness of immediate actions to mitigate meteorite climate crisis and impasses all around the world [10]. This is because the health of communities around the world has been challenging due the rapid increase of the global temperature. In accordance with their request, we should have to keep the average global temperature rise below 1.5C. Similar climatic narratives have been experienced in South Asian developing countries such as Sri Lanka, India, Pakistan, and Bangladesh [11-14]. Especially, Sri Lanka is as an Island country has dramatically been experienced mass flooding events for decades as consequences of rapid anthropogenic activities [15-19]. Sri Lanka has been experiencing torrential rains during the South-West monsoon period, generally it is lying from May to September every year [11]. This is because, in particular, rural areas of the country which are situated in the wet-zone catchment, experience tremendous consequences due to natural calamities like flood disasters.

According to the extant body of literature, currently there have been a new popup of research applications that concerned the abilities of social support networks and social capital mobilizations in healing disaster-driven community wounds [11, 15, 20]. Nevertheless, social network activities in community development have been researched for decades. Social networks have mattered in disaster risk reduction and management in many ways, this is because, basically social networks and community organizations are the first metaphors that touch the people's hearts at ground level basis and also they have much enough prowess to revivify victims' livelihoods. This may because the social support networks and related social capital have been considered as the panacea of disaster management [15]. Similarly, the existing body of literature exemplifies the pivotal narratives on how social networks and social capital have been mattered in terms of facilitating a plenty of ways to solve societal issues. In particular, dissemination of information, provision of shelters, water, foods, and basic needs, and evacuation practices etc. are paramount important mobilizations that made by social networks in the disaster events [20, 17]. Stevenson and Conradson point that based upon the 2010/11 Canterbury earthquake disaster event, the affected community received a range of supports, including material, monetary and emotional [21]. Mayer's study found that the non-financial supports are prominent among the supports mobilized through social networks compared to the financial supports [22]. In a case of Bangladesh flooding, Rotberg found that informal and formal social networks have played a cardinal role in providing and mobilizing many resources among rural flood victims [23]. Misra and colleagues demonstrated that social networks have facilitated in disaster preparedness and community resilience at different disaster phases regarding a cyclone-affected community in India [24].

In the Sri Lankan flood disaster context, the villagers have developed their own adaptation and resilience mechanisms, on the one hand, in order to mitigate adverse flood disaster impacts and on the other hand, in terms of developing livelihood revivifying practices thanks to the rich social support network legacies of especially in rural areas [11]. Especially, bonding, bridging, and linking social capital (e.g. structural) cumulatively mobilize through social support networks, when the community faces unexpected calamities such as flooding events and in the case of Sri Lanka, these practices have been evolved for decades traditionally thanks to the country's rich native ethos and cultural knowledge practices [11, 25]. Nevertheless, the research applications on social networks behaviors in the disaster management is lacking in the Sri Lankan context [26]. Since the climatic change calamities have been escalating around the world [27], the community resilience has come to the fore [28]. In this context, the objective of this research is to examine the behaviors of social support networks at different flood inundation phases, in five different flood affected rural areas in Sri Lanka. More importantly, this study will bridge the gaps of the extant body of literature by investigating the social network behaviors at different flood-inundated phases in flood affected rural areas on Sri Lanka.

2. Materials and Method

2.1 Study Area

The study conducted in Ovitigama Grama Niladari Division (GND), which is one of the mostly affected GNDs in Kuruwita District Secretariat Division (DSD), by 2017 mass flooding event, situated in Rathnapura district, Sri Lanka. By considering the flood damages that experienced due to 2017 mass flooding event, the study had been selected. More importantly, the study area is located in the wet-zone catchment of the country that has been experienced torrential rains during the South-West monsoon period. The study area has been experienced river flooding due to the overflow of Kuru River, which is one of the main tributaries of Kalu River, Sri Lanka. Geographically the study area lies between 5°.41′ – 6°.52′ north latitudes and 80°.15′ – 80°.28′ east longitudes. The current total population of Ovitigama GND is 1,147. According to Opanayake GN office, the unemployment rate of this GND is 4.24%. More importantly, the majority of population of this GND are occupied with agricultural practices such as tea plantation, paddy cultivation, and rubber/latex industry in addition to the gem mining industry. Many gem mines can be found within the close proximity areas to Kuru River and also nearby areas.

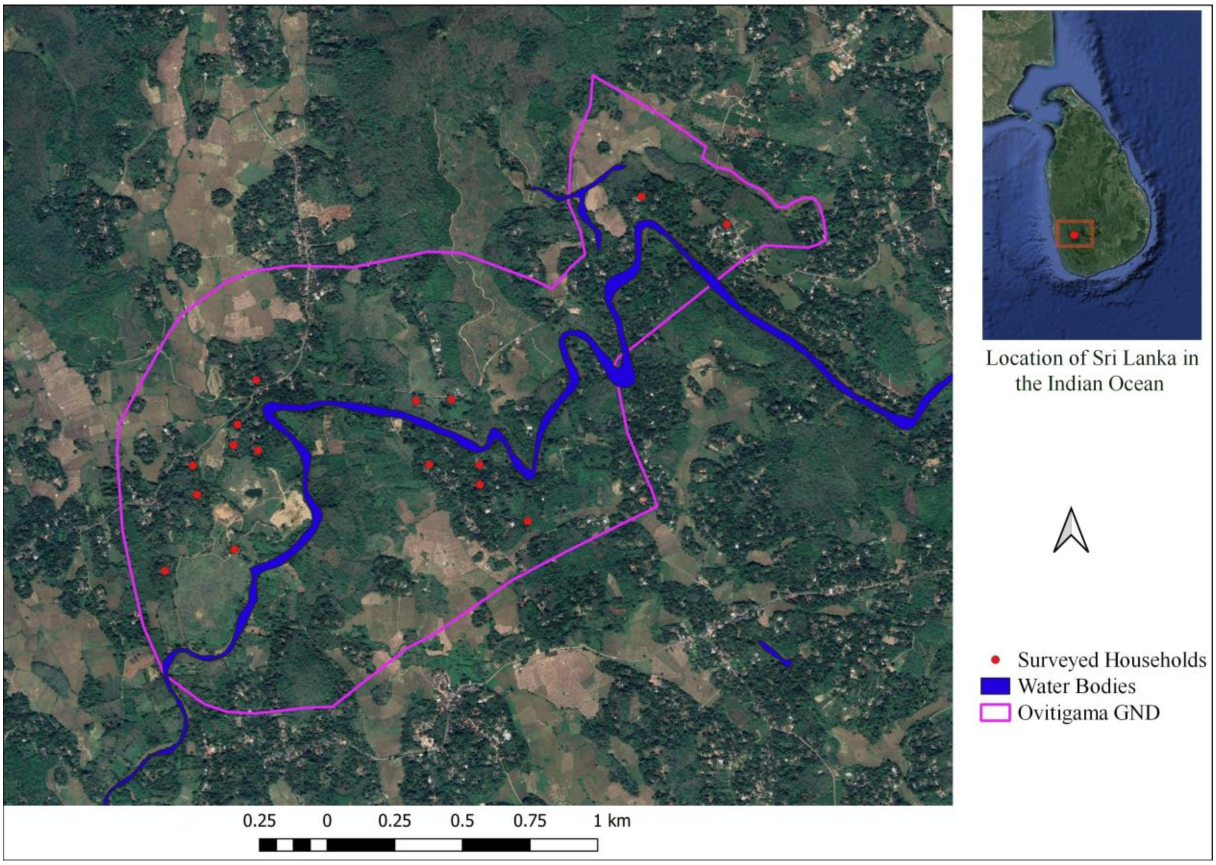

Figure 1. Relative locations of surveyed households and study area
Source: Cartographic design and compilation by the author, 2021.

2.2 Data Collection

The study considered primary data for social network analysis. The mostly affected households in the considered GND were listed, and the list has been used as the sample frame of the study. The simple random sampling procedure was occupied for primary data collection, since each and every observation unit (e.g. household) has an equal chance to be selected for the sample under that procedure. Particularly, interviewees were asked to participate in the household survey if they only had the experiences on the immediate past flooding event with their consent. Regarding the social network data, participants were asked to list out mostly helped personals (e.g. up to 10) including their relationships to households and the way/type of helps rendered and their residential location etc. The study considered three phases of flood inundation, such as before, during, and after inundation phases. The average time duration for a questionnaire/one household was ranged from 50 minutes to one hour, in some cases, more than one hour. In addition to the household survey, the study considered focus group discussions/FGD (n=2) involving around 20 participants. More importantly, the author also used self-field observation data especially regarding the understanding of social support network behaviors at before, during, and after flood inundation events. In particular, Grama Niladari Officer (GNO) also rendered his fullest support for identifying household and gathering primary data and information. GNO's past experiences on flooding events gave much information and pivotally important aspects on mass flooding events. Altogether with the respondents' experiences, they gave very much and overall understandings, and insights in terms of shaping the research outcomes. In other words, their credible experiences are basically very much worthwhile for advance the research applications of this study. The study also used the secondary data (e.g. GIS layers) such as administration boundaries, Satellite imagery (Google Earth) and water bodies.

2.3 Key Methods

The study mainly adapted the Social Network Analysis (SNA) method in order to systematically summarize and analyze the behaviors of social support network in the flood disaster events. The SNA mechanism is identified as one of the best methods in terms of understanding and analyzing the network behaviors of communities [29]. Especially social support network and interlaced community organizational activities have importantly been considered as influential proxies in disaster risk reduction and management [26], [20]. The software called UCINET (version 6) [31] was used for network data analysis and network graph visualization. In addition, QGIS 3.20.0 was used for the study area and household mapping purposes.

3. Empirical Results

The analysis of the findings was revealed that different social support network actors such as relatives, friends, neighbors, volunteers, and government officials (e.g. GNOs) have reciprocated different supports hands such as evacuation, provision of foods, water, other basic needs, and shelters, emotional supports, etc. at before, during, and after flooding phases at different magnitudes. More importantly at the after-flood inundation phase, there are many support ties were observed compared to the rest of before and during phases (see, Figure 4). The main reason behind these many reciprocal ties appeared at the after phase is to support flood victims to clean their contaminated (e.g. mudded) and damaged households and public places, and in particular, to render emotional supports for healing their flood disaster wounds. The social support networks have become pivotal especially in revivifying affected livelihoods.

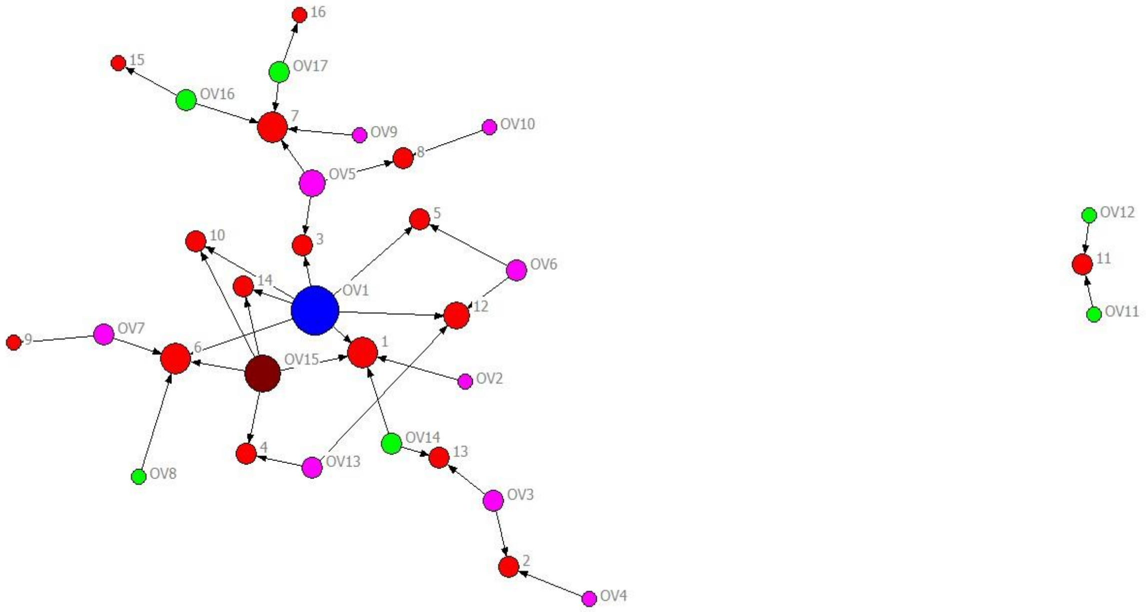

Figure 2: Social support networks at before flood inundation phase, Ovitigama GND. *Notes: The size of each node represents their degree density (proportional). Colors of nodes: Red for surveyed households, Blue for GNO or authorities, Pink for relatives, Green for neighbors or friends, Brown for volunteers.*

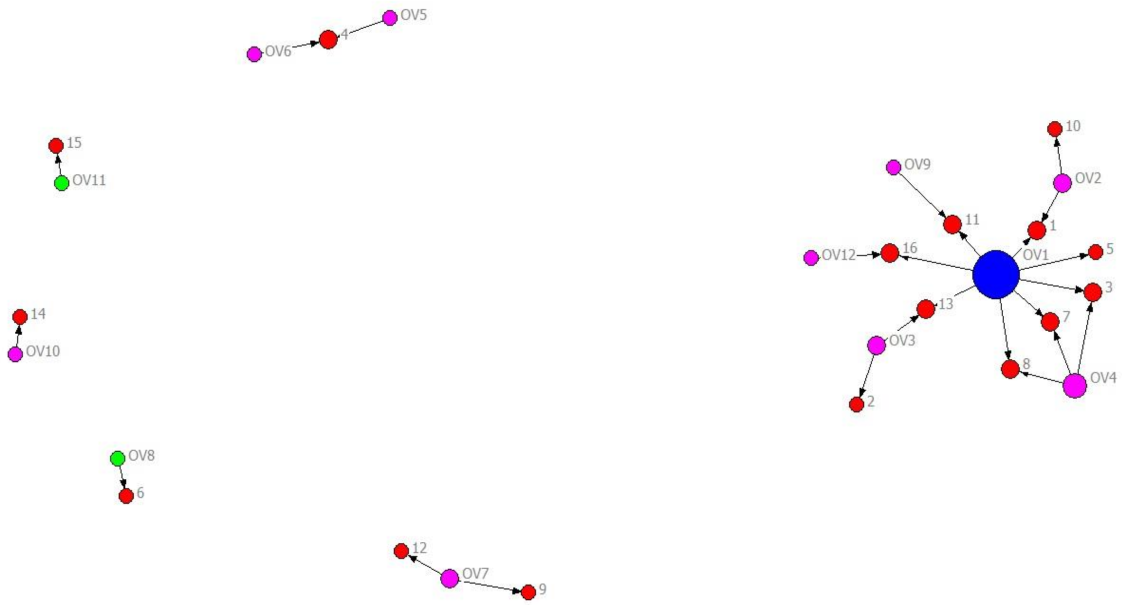

Figure 3: Social support networks at during flood inundation phase, Ovitigama GND. *Notes: The size of each node represents their degree density (proportional). Colors of nodes: Red for surveyed households, Blue for GNO or authorities, Pink for relatives, Green for neighbors or friends.*

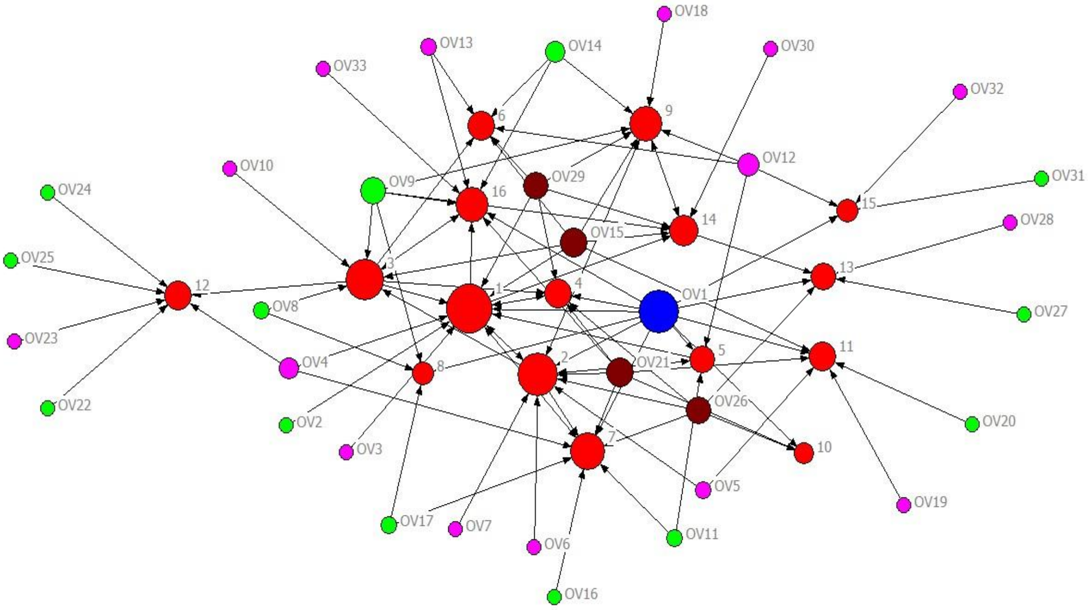

Figure 4: Social support networks at after flood inundation phase, Ovitigama GND. *Notes: The size of each node represents their degree density (proportional). Colors of nodes: Red for surveyed households, Blue for GNO or authorities, Pink for relatives, Green for neighbors or friends, Brown for volunteers.*

The study revealed relatively low network support patterns at the before and during flood inundation phases. For example, at the before phase, almost all the household (except the household # 11) have intertwined with different helping ties in order to respond the rushing floodwaters. On the other hand, no perfect links found among GNO and some of households, despite the majority of household have exemplified very close links with the GNO. The credible evidence (e.g. filed observations) also proved that the GNO has hardly been worked to reciprocate and mobilize resources among flood victims. Particularly, the GNO has continuously been involved with support activities at during and after flood inundation events as a responsible government agent. More importantly the respondents revealed their experiences of flooding events. It is observed that the relatives (pink colored) are predominant among the reported network actors in the all the phases compared to the rest of actors. It is appeared more network activities of relatives in the after-flood inundation phase rather than to their activities in the rest of inundation phases (Figure 4). On the other hand, very few (n=2) neighbors or friends (green colored) reported at the during phase while at the after phase (n=13) and at the before phase (n=6) indicated many respectively. Regarding the volunteers, none of actors reported at the during phase, compared to the before (n=1) and after phases (n=4). Especially, at the after phase, many ties are appeared since everything including inundated households and public places have to be repaired, rebuild and reinstalled.

One of the pivotal things is observed that they were provided fiber or wooden boats by disaster management authorities in order to provide facilities including floods, water and assistance for flood victims, in particular, at the during flood inundation phase. Despite, the majority of flood affected household members of Ovitigama GND urged that one of their urgent needs is to have around five to eight wooden or fiber boats for their evacuation plans (FGD-2). This is because, they have been experienced a rush and impasse situation, when many households are inundated and requested to being evacuated. Indeed, the field observations also proved that their request is fairer and need to be answered. It will absolutely help to be invigorated their livelihoods. Since, no schooling members also recorded in some affected households (Table 1).

Table 1: Sociodemographic characteristics of surveyed households

Key Components	Percentage (%)
Age groups	
<15	5.2
16-24	10.1
25-40	35.2
40-64	40.1
>65	9.4
Gender	
Male	48.8
Female	51.2
Education Background	
No Schooling	5.5
Below Primary	62.3
Above primary and secondary	30.1
Above Secondary	2.1
Employment Environment	
Employed	61.7
Unemployed (including students and kids)	38.3
Marital Status	
Married	77.5
Single	21.6
Other (separated, divorced, and widowed)	0.9

More importantly community organizations such as *Grama Sanwardena Samithiya, Maranadara Samithiya, Kantha Samithiya, Dayaka Sabawa etc.* have been shaping the village level resource mobilization process in terms of revivifying the flood affected livelihoods in many possible ways. Of course, such community-level organizations help to enrich the village level social fabrics/ties and social capital metaphors. Even though each and every community organization has their own objectives and missions, they cooperatively work to strength helping hands for the flood disaster victims. Their trusts, cultural and religious practices, norms, and beliefs have been intertwined people of their communities productively. This is because Ovitigama GND also exemplifies quite rich social network and social capital circumstance.

4. Discussion

The study demonstrated that almost all the surveyed household have received one or more supports form the social support networks. Social support networks are intertwined through different actors such as relatives, neighbours or friends, and volunteers and their ties. Relatives identified as the predominant networks actors that mobilized helps and resources among flood affected households, compared to the rest of actors. Of course, it is imperative that the family networks and their bonding ties have been become pivotal when the disaster events unfolded [11]. Spatial variation of flood inundation events has adversely been affected the pervasiveness of social support networks and resource mobilization [17]. In contrast, some affected households have not been received enough support due to the accessibility of variegated geographical settings. In some cases, the respondents pointed out that their households didn't receive adequate supports due the poor network situation of their households. Especially, they are internal migrator and have been dwelling there in Ovitigama GND for few years. This is one of the disadvantages of social ties and support networks [11]. The main reason behind this situation is that the trust and the longevity of the membership of village organizations [15]. On the other hand, very few members of focus groups discussion revealed that they experienced such lopsided and unfair treatments may be due to their personal political ideologies (FGD-1). Of course, any kind of spurred exasperation can be arisen due to lopsided practices in particular, regarding the post-disaster management activities. Nevertheless, GNO emphasised that he did everything in order to revivify the flood affected livelihoods of Ovitigama GND and he treated each and every household in a fair-minded manner by considering their damages that experienced by past flooding event. Field observations suggest that collaborative supports are fundamentally pivotally important for helping flood victims to clean their mudded and contaminated houses and premises and until covert them into better places with decent living conditions. Of course, a range of helping ties have been reducing victims' perturbations, depressions, many mental illnesses and probably post-traumatic stresses [11]. In some villages, they have own contingency plans and indeed those are very crucial to face for the next calamity probably with almighty beatings and consequences. This is because it is well understood that keeping victims' mental health at a good level is a foremost important factor in disaster recovery practices and also to avert cascade disasters. These helping ties turned impasse situations into manageable circumstances, thanks to their altruistic nature helping each other. These notions have come to the fore in the disaster risk reduction and management practices. Personal observations and experiences proved that community support networks make big advantages for people who are living in often perilous flood plains.

More importantly the study demonstrated that the social support network legacies have evolved at before, during, and after flood inundation events. This evolutionary pattern exemplified that the structural changes of network graphs [17]. Moreover, the *de facto* tradition of helping others and their altruistic nature exemplify the sophisticated native ethos and rich cultural values of rural communities [11], [25], [30]. Yet, the rich social networks and social capital mobilizations can be observed among rural communities compared to the urban context of Sri Lanka, especially in the disaster events. This is because some good and material donations that received affiliated to 2017 mass flooding events have not been operationalized/utilized even after 6/7 months of the event. Especially school items such as bags, writing/exercise books, cloths, and many other items are appeared in the stores, according to the officials of Kuruwita DSD office. The various activities of reciprocal support networks are based upon the local level community organizations and their affiliated associations [20]. In particular, a range of social ties and related reciprocal activities have widely been shaped by the community level organizations. This is because complementary associations can be often seen between the reciprocal support networks and the community organizations. Of course, it is very obvious that much of networking activities can be observed in the areas with dense organizational and related social networks. Findings of the study show that the similar narratives regarding the formation of social support networks. All the forms of reciprocal activities enormously influence to improve and shapeshift of the resiliency of disaster victims [28], [20]. This is because reciprocal support network legacies have significantly influenced on rebuilding the resilience of flood affected livelihoods in many ways. Volunteerism is also identified as one of the key metaphors in the community disaster response networks for improving the resilience of victims [15]. Canterbury earthquake also exemplified the similar narratives [21]. They identified social networking as one of the ample components that provide a range of information and external supports in terms of maintaining the daily lives of disaster victims. On the other hand, the spatiality of social ties can be considered as the cardinal variable that governing the context of reciprocal support in the disaster events [20], [26]. More importantly, many of villagers shared their knowledge and knowledge practices with flood victims in good faith.

5. Concluding Remarks

Based on the empirical findings, this study demonstrates that social support networks significantly influenced for flood disaster response and recovery and a range of reciprocal exchanges have mobilized in terms of revivifying of adversely affected livelihoods by 2017 flood inundation event. Moreover, the study revealed undeniable evidence of evolutionary changes of support networks over time at different flood inundation phases. In particular, the helping ties have increased from before phase to during phase related to many surveyed households. And then, these reciprocal ties have further increased in the after phase in related to almost every household. The study also indicated that comparatively less reciprocal support ties are engaged in the low-depth flood inundated areas. And also, quite different mode of ties was observed in geographical variegated flood-inundated settings. In line with the study findings, it is observed that pervasive reciprocal support networks have potential strengths of reducing flood disaster risks and to heighten disaster mitigation practices through by many folds involving with a range of network actors such as relatives, friends, neighbours, government officers, and volunteers. Also, this study makes good assessment on flood disaster preparedness and recovery in Ovitigama GND area by analysing affected households' networks patterns and their evolutionary nature over time. Of course, abovementioned merits are solely based upon the sample size. The household survey engaged with 16 flood affected households belonged to Ovitigama GND that located in flood inundated rural context. This is quite a big task regarding collecting primary data on social networking at three different flood inundated phases. Overall, this study makes some inference and contributions to the debate of reciprocal supportive network legacies on flood disaster management, recovery, and risk reduction and also this study bridges the gaps of the extant body of literature of disaster management discourse in Sri Lankan context.

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Conflict of Interest

The author declares that he has no any of known competing financial interests or personal relationships that could be influenced the demonstrated facts in this paper.

Author Contribution

Author A. Karunarathne conducted the data collection, analysis and the preparation of the manuscript.

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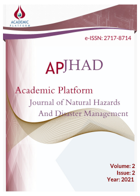

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Disaster and Livelihood of the Affected Population: Case study of June 2013 disaster in Rudraprayag district of Uttarakhand

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Abstract

Economic impact of disaster and utilisation pattern of the relief is assessed though semi-structured questionnaire and focused discussions in Rudraprayag district of Uttarakhand in India that was devastated by floods in June, 2013. It is observed that in the absence of risk transfer tools the disaster affected population, particularly those engaged in petty business and representing weaker sections of the society, find it hard to replenish their productive assets lost in the disaster due to (i) the relief amount being significantly less than market value of lost assets, (ii) limited savings, (iii) relief amount spent on non-productive household purposes owing to reduced income in the post-disaster phase, and (iv) poor assess to institutional financing. The state is therefore advised to initiate an organised scheme with the involvement of financial institutions to facilitate replenishment of productive assets lost in disaster incidences rather than providing cash relief, and ensure insurance of the assets so created as the voluntary adoption of risk transfer tools is unlikely to come by soon.

Key words: Economic recovery, risk transfer, disaster relief, Mandakini Valley, Uttarakhand Himalaya

1. Introduction

Located in the Himalayan region Uttarakhand province of India is vulnerable to a number of natural hazards that include earthquake, landslide, flood, and flash flood and these are owed to geological history, physiography, geo-tectonic set up and meteorological conditions of the terrain [1-3]. Except earthquake, other hazards generally occur during the monsoon period - rainy season in the Indian subcontinent [4-6] and apart from the loss of human lives, these result in loss of productive assets adversely effecting quality of life of the affected population.

In the summers of 2013 Uttarakhand received abnormally high rainfall due to the clash of southwest monsoonal winds with the westerlies that resulted in massive floods particularly in the 05 northern districts (Figure 1); Rudraprayag, Uttarkashi, Chamoli, Bageshwar and Pithoragarh [7-13]. Of these, Rudraprayag was the worst affected district and the floodwaters caused massive loss of human lives besides damage and destruction of infrastructure and property, particularly in the Manadakini valley that houses Kedarnath shrine which is highly revered by Hindus [12, 13].

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The floods disrupted all tourism and pilgrimage related activities as the National Highway connecting Rudraprayag and Chamoli districts remained closed for a long period (Table 1). Moreover, fear psychosis created by the death of more than 4000 persons desisted people from venturing to the region for a long time which is evident from sharp decline in the number of people visiting Kedarnath even after one year of the disaster (Table 2). This resulted in substantial reduction in the income of the people of the area engaged in various pilgrim and tourist related activities and business.

Table 1. Disruption of surface connectivity along NH 58 and NH 109 connecting Rudraprayag and Chamoli districts after 16-17 June, 2013 disaster. Data source: *State Emergency Operations Centre, Department of Disaster Management, Government of Uttarakhand.*

Sl. No.	**Highway**	**Days for Which the Connectivity Was Disrupted**					**Surface Connectivity Disruption (In %)**
		June (30 days)	July (31 days)	August (31 days)	September (30 days)	Total (122 days)	
1.	Rishikesh Badrinath (NH 58)	15	20	17	13	65	53.3
2.	Karnaprayag – Kedarnath (NH 109)	13	21	18	13	65	53.3

The disaster of June, 2013 was highly publicized by the media and galvanized by the sufferings of both local people and ones stranded due to the incidence at different places there was massive inflow of relief material to the affected area. This paper is an attempt to analyze the state of replenishment of productive assets lost in the disaster and impact of relief on the economy of Rudraprayag district.

Table 2. Number of persons visiting Kedarnath in the period 2011 – 14. Data source: *Uttarakhand Tourism Development Board, Dehradun.*

MONTH	**2011**	**2012**	**2013**	**2014**	**DECREASE IN 2014 (IN%)**
MAY	2,45,821	2,98,182	1,49,689	13,823	94.0
JUNE	2,49,386	1,96,830	1,82,551	14,091	93.3
JULY	29,216	27,712	-	3,041	89.3
AUGUST	11,759	11,496	-	944	91.9
SEPTEMBER	20,746	12,823	-	3,796	77.4

2. Disaster relief in India

Insurance is often considered an effective tool of post-disaster economic recovery [14, 15]. It however does not have significant penetration amongst the masses in India, particularly in the rural areas where majority of the population resides [16]. On the aftermath of a disaster the affected population, having lost its productive assets and left with little resources to face the situation, therefore looks upon the state for assistance. Keeping with the spirit of a welfare state there exists an institutional arrangement of providing relief to the disaster affected population.

Financial receipts in the central government exchequer in India are earmarked for expenditure under various heads, and also shared with the provincial governments in accordance with the recommendations of the Finance Commission that is set up every 05 years in accordance with Article 280 of the Constitution of India [17]. In accordance with the recommendations of the previous Finance Commissions and Sections 46 and 48 of the Disaster Management Act - 2005 [18], resources for disaster related contingencies are allocated under National and State Disaster Response Funds (NDRF/SDRF) for central and provincial governments.

In the event of a notified natural calamity the affected provincial government utilizes the funds available under SDRF for providing relief to the disaster victims. Though generally provided in cash, attempts are underway to transfer it directly to the bank account of the beneficiaries. The quantum of relief for the identified losses is in keeping with the notifications to this regard by the Ministry of Home Affairs, Government of India. As indicated clearly the relief is not intended to compensate the loss suffered by the individuals and is only for immediate sustenance of the affected population. The relief amount therefore has no direct relationship with the economic value of the assets lost in the disaster. Moreover, relief out of SDRF is not provided for the loss of commercial assets as the ones managing commercial enterprises are expected to take resort to suitable risk transfer mechanism on their own.

The relief is however much less than the market price or cost of replenishment of the assets lost due to disaster. Owing largely to other related post-disaster contingencies and familial requirements, the disaster affected families often end up utilizing the relief amount on non-productive expenses which has adverse impact on the quality of life of the disaster affected population.

3. Materials and Methods

3.1 Study area

Rudraprayag district has a population of 2,42,285 of which 52.77% are females. 95.9% population resides in its 653 villages and the workforce constitutes 46.7% of the population of which 76.4% is engaged in agriculture [16]. Rudraprayag, the headquarter of the district is located at the confluence of Alaknanda and Mandakini rivers.

Apart from the district headquarter Agastmuni, Okhimath, Guptkashi and Tilwara are other urban areas while Kedarnath, Kartikswami, Kalimath, Madhyamaheshwar, Ransi, Trijuginarayan, Tungnath and Onkareshwar (Okhimath) are major Hindu shrines attracting people from across the country in large numbers (Fig. 1). Most shrines remain snowbound during the winters and are accessible between May – June to October – November. These are visited by people in large numbers before the onset of monsoonal rains as that period coincides with summer vacations in the schools and visiting the mountains provides people solace from scorching heat of the plains. Moreover, this period is generally rain free and thus the visitors do not have to face inconvenience caused by landslide induced traffic disruption.

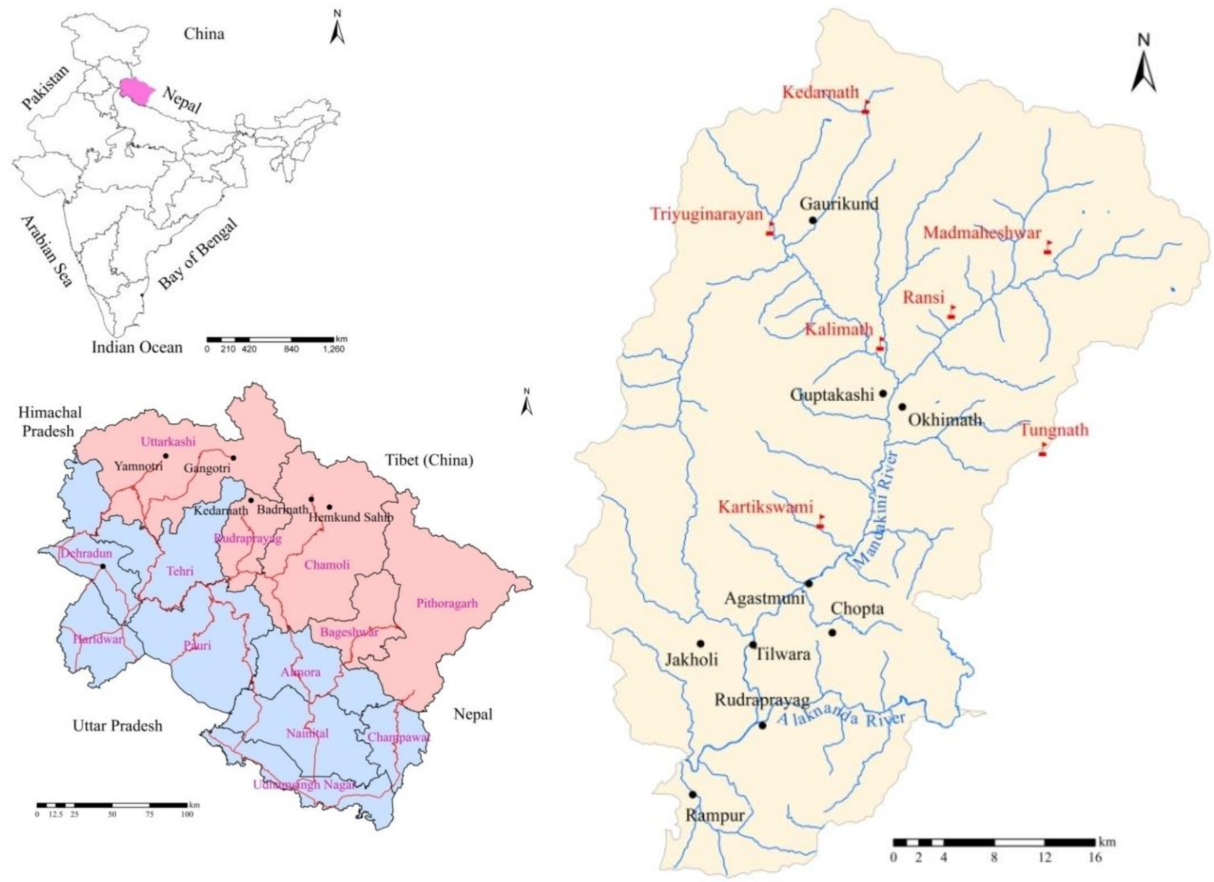

Figure 1. Map depicting study area (Right), five flood affected districts of Uttarakhand depicted in red color (lower left) and Uttarakhand in the map of India (upper left).

3.2 Data collection and Survey

Particulars of the individuals who lost their productive assets and relief provided were collected from the local administration. Details of the relief amount, distribution strategy and problems encountered in distribution were gathered through interactions with the officials of the local administration. This information was utilized for planning the coverage of the study ensuring fair representation of the entire district. A total of 417 disaster affected families were covered by this study (Table 3). Semi-structured questionnaire and focused discussions were used for assessing the impact of disaster and utilization pattern of the relief.

Table 3. Number of respondents under each category of losses covered under the study.

SL. NO.	LIVELIHOOD ASSET	RESPONDENTS
1.	Livestock	156
2.	Agriculture land	102
3.	Petty business	65
4.	Medium and large business	94

4. Impact on livelihood assets

For the purpose of present study productive assets were classified into livestock, agricultural land and business assets. Of these relief out of SDRF is admissible for the loss of livestock and agricultural land only. In view of the severity of June 2013 disaster provision of relief was however made for some commercial assets by the provincial government out of Chief Minister Relief Fund. Repayment of the loans was also deferred and both electricity and water dues of the commercial establishments were waived off.

In order to better understand the impact of disaster on the quality of life and spending pattern of relief amount a semi-structured questionnaire was utilized for gathering the relevant information from the affected population. Focused discussions were also organized for assessing the perception of the people on related issues.

4.1 Livestock

Animal rearing was mainstay of the economy of the region and these were utilised for cross border trade with Tibet. Though the animal stock has depleted sharply since the closure of trade after Sino-Indian conflict of 1962, animal rearing still remains a major economic activity in the hills, and substantiates household income besides enriching the food.

The livestock commonly reared by the masses in the area includes cow, ox, goat, sheep, horse and mule. Cow and goat provide milk products and meat respectively while ox is utilized for agricultural purposes. Compared to these horse and mule are put to direct commercial use and utilised for transporting people and supplies as also construction material along various trekking routes and also to villages not connected by road. Large population of the area is engaged in these activities that revolve around various pilgrim and tourist destinations, which include Kedarnath, Kartikswami, Madhyamaheshwar, Ransi, Trijuginarayan and Tungnath. This is a major source of income for these people.

156 families that had lost mules and horses were covered by the present study. Of these 33.3% had lost one animal while the others had lost two. No one had insured the animal and this was attributed to lack of information. All the families received relief of Rs. 50000 for the loss of one animal and this amount included the relief admissible out of SDRF. Market price of mule and horse being significantly higher 75.6% respondents were not satisfied with relief amount and 78.2% favoured replenishment of assets lost in disaster rather than cash relief.

In order to continue the livelihood 52.6% purchased a mule after the disaster and for this 30% resorted to borrowing. Not familiar with institutional financing 66.7% had to however manage loans from friends and relatives. Being peak of the pilgrim season most persons capable of handling the mules and horses were in the Mandakini valley when the disaster took place and many of these perished in the incidence. 38.9% of the families not replenishing the animal had lost the family members engaged in this activity and there was no one in the family who could continue the engagement with the animals.

With disrupted tourist and pilgrim activities most households were left with no source of income and therefore another 38.9% could not replenish the lost animal as the relief amount had to be spent on routine household expenses. Age and psychological fear of venturing into the Mandakini valley were the reasons for 5.6% each to discontinue this profession.

47.4% respondents spent the relief amount on routine non-productive household expenses. Only 7.7% consulted other family members before making the spending decision and as the head of the family they did not consider it necessary. With only 13.5% investing the relief amount on the creation of alternative productive assets others repented their decision to spend the relief amount on non-productive purposes.

The people do realize the importance of insurance and accept that they would have received a better deal had their animals been insured. They also accept that their region is vulnerable to disasters and can be affected again in future. Insignificant proportion of the respondents however agreed to insure their animals and inability to pay the premiums on a regular basis was put forth as the main reason thereof.

4.2 Agricultural land

Even though agriculture is the mainstay of the economy of the province most landholdings, particularly in the hilly region that comprises ~86.1% geographical area of the province, are small and marginal - less than 2 hectares. These are at the same time rainfed and fragmented - scattered over large area. Moreover, the agricultural terraces developed over the hill slopes are vulnerable to being overrun by landslide debris and instability induced by toe erosion by rivers and streams.

Of the families losing significant proportion of their agricultural land due to disaster, 102 that were largely dependent on agriculture were selected for the purpose of present study. Of these only 21.6% utilized the relief amount for the purchase of agricultural land at an alternative place and for the repair and upkeep of the damaged fields.

33.3% respondents availed loans on the aftermath of the disaster of 2013 but only 16.7% each took loan for agricultural operations and starting new business, while the majority (55.6%) took loan for the construction of house or for other non-productive purposes. Loan was availed from formal financial institutions by 61.1%.

As regards utilization of relief amount received for the loss of agricultural land, 21.6% utilized it on the repair and reconstruction of their house that was damaged by the disaster while 51.0% spent it on routine household expenses.

All the respondents were unanimous over relief amount being much less than prevailing market rate of land in the area and this was put forth as the main reason for not purchasing land. No respondent was therefore satisfied with the relief and all were unanimous that instead of cash relief the state should provide land equivalent to that lost in the disaster.

As assessed, the disaster has weakened economic state of all the respondents and it is attributed to (i) loss of land, (ii) inability to purchase land in lieu of the lost land, (iii) lacking investment on other income generating assets, and (iv) savings having spent on routine household expenses. All the responders accepted that the region could be affected by disasters in future as well but were reluctant to insure their agricultural land. Recurring payment of premium seemed a major economic burden to almost all.

4.3 Petty business

Agriculture in the hills being subsistence type, most families substantiate their household incomes through allied activities - animal rearing, temporary menial jobs and involvement in tourism and pilgrimage related activities [19, 20]. Apart from this a number of persons operate commercial vehicles and work in the hospitality sector in various capacities while some are engaged is small business of their own. All these activities ensure cash flow so as to fulfill non-farm family requirements.

65 persons engaged in small business were covered by this study. These were mostly tea and food stall operators and persons selling various other items to tourists and pilgrims by the road side, as also along the foot trek between Gaurikund and Kedarnath. Average monthly income of these persons ranged between Rs. 4,000 and 8,000. They however earned much higher amount during the tourist season. Till the disaster of 2013 all the familial household expenses of these persons were being met from this activity.

Of the persons included under the survey 61.5% incurred loss of business infrastructure and supplies during the disaster while the rest were forced to close the business as there was significant decrease in the number of persons visiting the area (Table 2).

A major habitation, Rambara, located on the foot trek from Gaurikund to Kedarnath was totally wiped out in the floods of 2013 [8,11,13] and subsequently the foot trek was aligned along the left bank of Mandakini. The persons operating along the old foot trek on the right bank of Mandakini were thus left with no option but to close their business.

62.5% respondents were assessed as being eligible for relief and operating business on public land was the main cause of disallowing relief to the others. The relief amount was however spent on routine household expenses, as these persons were left with no other source of income after the disaster.

Only 46.2% respondents started the business again in 2014 – 15. Widening of the road, loss of land, realignment of the foot trek and lack of money were the main reasons for not continuing with the profession. The persons discontinuing their business were working in the construction industry as daily wage earners.

No one resorted to loan of any sort for restarting the business. Economic condition of all was worse compared to 2013 and they had spent whatever little savings they had for meeting routine household needs. As expected, all the responders expressed inability to pay the insurance premium as their income was not significant.

4.4 Medium and large business

94 medium and large business establishments spread across the district were covered under the present study. Except for 3.2% others were doing good business till the time of 2013 disaster and their monthly income ranged between Rs. 4,000 to 4,00,000.

All were unanimous that their business was adversely affected by the disaster of 2013; 43.8% attributed this to reduced demand due to disrupted connectivity, 20.8% to migration of people after the disaster and thus reduced buyers, 18.8% to disaster induced loss of business infrastructure, 9.4% to people buying on credit going missing and 7.3% to disrupted supply chain. Due to reduced income respondents were finding it hard to repay their loans. The recovery being long drawn most respondents had spent their savings in managing routine household affairs.

Being located at relatively safe places business establishments of most respondents were saved from direct impact of the disaster. Moreover, with steady income over long time the respondents had appreciable savings that helped them overcome business disruption. Continued dealings with the financial institutions helped them access loans to further strengthen and diversify their business. 30.9% respondents resorted to loan from different financial institutions after the disaster of 2013 for strengthening their business and average loan amount was Rs. 3,70,000.

This category was therefore not affected significantly by the disaster. The impact on business was assessed as being severe by 63.9% and moderate by 16.9%.

37.2% respondents agreed to insure their business assets. Of these assets of 42.9% were however already insured. Minimal impact on the business assets seemed to deter the majority from insuring their business.

5. Discussion and Conclusion

In the year 2013 Uttarakhand witnessed a major disaster and Rudraprayag was amongst the worst affected districts. Routine income the people engaged in almost all vocations witnessed sharp decline on the aftermath of the disaster that is attributed to disruption in tourism and pilgrimage related activities. This forced people to spend significant proportion of their savings on routine household expenses and except for medium and large business operators all others were left with no savings to bank upon in future.

The disaster caused massive loss of productive assets of the people - livestock, agriculture land and business assets. The impact as brought out by the study was worst on the ones representing lower socio-economic strata of the community and engaged in petty business. Majority of these persons were operating their business informally and on public land. They were therefore treated as encroachers and not provided relief. Otherwise also, their routine turnover was not significant and they had limited savings. With reduced or no income, they spent whatever little savings they had and were left with no other option but to work as daily wage earners to make the ends meet. Moreover, these persons had limited interaction with formal financial institutions and therefore they could not get financial support to restart their business.

Except for the families that lost the persons engaged in the activity together with ones deciding to discontinue the profession for personal reasons, most households engaged in ferrying tourists, pilgrims and supplies purchased the lost asset. The relief amount being far less than the replenishment cost or market price of the animal, a number of families resorted to loan while the others utilized their household savings to bridge the gap. Like petty business operators this group, representing lower social strata of the community, could not assess institutional financial support and had to resort to loan from friends and relatives.

The difference between market price of land and relief amount being exorbitant, only a few families dependent solely on agriculture could purchase the land in lieu of that lost in the disaster. These families however had assessed to formal financial institutions and availed loan for other purposes; particularly for construction of house.

Due to the inbuilt resilience the persons operating medium and large business managed to overcome the situation relatively easily. Though this group witnessed a lean period in their business after the disaster of 2013, their assets were largely unaffected as these were well built and located at relatively safe places. Moreover, this group also had assets and savings to tide over the lean period. Regular interaction and dealings with financial institutions together with their socio-economic status helped them avail institutional financial support for strengthening and diversifying their business.

Disaster induced loss of productive assets and their non-replenishment due to various reasons is observed to be a major hurdle in economic recovery particularly for petty business and other small-time operators. It is brought out by the study that a large proportion of the persons fail to recover from the impact of the disaster and the quality of their life deteriorates perpetually as is evident from large proportion of the petty business operators working as daily wage earners.

Relief is generally not provided by the state for the loss of business assets due to disaster and even where it is provided in some exceptional circumstances it is not enough for the replenishment of the lost assets. This has adverse impact on the livelihood strategy and quality of life of the affected population, particularly the ones engaged in petty and small business.

It would however not be feasible for the state to provide relief for the loss of business assets and insurance is the most viable option for ensuring post-disaster economic recovery. With small business operators that are often the hardest hit by disaster incidences, not in a position to purchase available insurance cover the state needs to conceive, design, promote and subsidize suitable risk transfer instruments to ensure coverage of all engaged in business. This could be done by making insurance an essential condition for operating any business.

Even though relief is provided by the state for the loss of agricultural land and farm animals the affected families fail to replenish the lost asset due to high market price of these. Moreover, due to reduced income in the post-disaster phase most relief amount is spent on nonproductive and familial requirements.

Loan linked replenishment of productive assets lost in disaster through suitable linkages with financial institutions and discontinuing the current practice of providing cash relief for the loss of productive assets could be a viable solution to this problem. Moreover, as has been highlighted by some studies cash relief after a disaster depresses economic growth [21] and therefore the state should focus on the replenishment of lost assets. While replenishing productive assets state also needs to ensure that the assets being created are insured with a provision of premium deduction for a long duration at one go at the very beginning.

Acknowledgements

Inhabitants and administration of Rudraprayag district are thanked for cooperation in the field studies. Colleagues at Disaster Mitigation and Management Centre and Uttarakhand State Disaster Management Authority are thanked for support. We thank all the reviewers for their comments that helped to improve the manuscript significantly.

Author Contribution

SK undertook fieldwork in the affected area and collected the data through interaction with different stakeholders. PR designed the questionnaire, analysed the data collected and prepared the manuscript.

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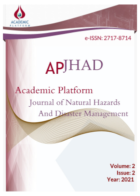

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Fiber Based Modeling Strategies of RC Columns

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Abstract

Although experimental studies have proven as the most effective method, its high cost has provoked researchers to seek alternative approaches. The increase in computational power in the 21st century provides the opportunity to numerically model experimental studies with various programs. This study examines the comparison of force-based element and displacement-based element in columns using nonlinear fiber elements. Within the scope of the study, OpenSees program is employed for reinforced concrete (RC) columns selected from the PEER (Structural Performance Database) site. Physical regularization technique is applied to the elements while considering the plastic hinge length of the columns. The aim is to compare the employment of the force-based (FB) element and displacement-based (DB) elements in RC columns in terms of number of elements and integration points, to simulate the global behavior of the columns numerically, and to optimize the parameters that affect the results.

Key words: Fiber Elements, Reinforced Concrete, Calibration, Finite Elements, OpenSee

1. Introduction

Experimental studies are one of the most effective methods in examining the behavior of structures/structural components. However, their high cost sought researchers to find out new alternatives. While the computational power has increased, numerical investigations are the potential to have information about the behavior of the structural element without performing experimental work. It is, however, necessary to verify that the models made in these programs can give results close to the experimental studies at a sufficient level. Meanwhile, the verification process contains calibration steps as well. If the obtained results via the numerical simulation are matched, the behavior of the building elements can be obtained in a short time frame.

In the experimental tests, it is observed that the nonlinear behavior of the element is accumulated in a certain length along with the height, which can be called the damage zone. In order to have a better understanding of the calibration strategies applied to the models in this study, it is necessary to mention the concept of plastic hinges. Plastic hinges are junction points that carry bending moment up to a certain level and allow rotation in bending moment magnitudes exceeding their capacities. Here, the point that separates the joint from the plastic hinge is that it tolerates some degree of the moment. Many have worked on experiments, and several empirical models have been developed because the plastic hinges have complicated interactions between constituent materials and high nonlinearity of materials. These models are shown in
Table ***1***.

* Corresponding Author

Table 1. Empirical plastic hinge length calculation proposed by researchers

The Equations	Reseachers	Definition of the parameters
$L_p = 0.18L + 0.021 d_b f_y$ *for monotonic loading* $L_p = 0.12Ls + 0.014\, a_{sl} d_b f_y$ *for cyclic loading*	Panagiotakos & Fardis [1]	L_p: equivalent plastic hinge length db: diameter of longitudinal reinforcement f_y: yield strength of longitudinal reinforcement
$L_p = 0.8 k_1 k_3 \left(\frac{L}{D}\right) c$	Baker [2]	k_1: equal to 0.7 for mild steel k_3: 0.9 for cold-worked steel c: the neutral axis depth L: columns length D: the section depth to assess the response of reinforced concrete beams
$L_p = 0.25d + 0.075z$	Sawyer [3]	d: distance from outer compressive fiber to centroid of tensile reinforcement z: spacing of transverse reinforcement
$L_p = 0.5d[1 + (0.4/\sqrt{d})](\frac{z}{d})$	Corley [4]	d: distance from outer compressive fiber to centroid of tensile reinforcement z: spacing of transverse reinforcement
$L_p = 0.5d + 0.05z$	Mattock [5]	d: distance from outer compressive fiber to centroid of tensile reinforcement z: spacing of transverse reinforcement
$L_p = 0.08d + 0.022\, d_b f_y$	T. Paulay, M.J.N. Priestley [6]	f_y: yield strength of longitudinal reinforcement d: length from section of maximum moment to the point of inflection d_b: bar diameter for the longitudinal reinforcement
$L_p = 0.5(1.06d + 0.13\,\rho V)\, d$	Naaman et al. [7]	ρ: reinforcement ratios d: distance from outer compressive fiber to centroid of tensile reinforcement V: shear force
$L_p = 0.05L + \frac{0.1 f_y d_b}{\sqrt{f_c}}$	Berry et al. [8]	f_c: concrete compressive strength f_y: yield strength of longitudinal reinforcement d_b: diameter of column longitudinal reinforcing steel L: column length from point of maximum moment at column base to point of zero moment at
$L_p = h$	Sheikh et al. [9]	L_p : Equivalent plastic hinge length h : Total column depth
$L_p = (0.3 + 0.18\rho)\, d$	Tariq et al. [10]	ρ: reinforcement ratios d: distance from tensile longitudinal reinforcement to the extreme compression fiber

Distributed inelasticity elements are employed in earthquake engineering applications such as research or professional engineering purposes. Concentrated plasticity and distributed plasticity are the two general approaches used in the numerical analysis of frame structures. The concentrated plasticity assumes that the nonlinear behaviour is in a limited zone, mainly in a null or zero-length element, and the remaining part of the element behaves linearly. Although concentrated plasticity is an approach that has been used and accepted for many years, the distributed plasticity approach has developed considerably with the advancement of computer power. With distributed inelasticity models, the inelasticity is dispersed at each section throughout the member. The inelasticity of the frame is controlled by each integration point. This approach shows a profound closeness to the experimental results [11]. The distributed plasticity is also explored in two main finite element formulations: force-based and displacement-based formulations within the fiber element concept (in addition, OpenSees offer an element mixing force-based element and concentrated plasticity as a third option, named "beamwithhinge element"). The fiber element in the distributed plasticity is a method based on uniaxial stress-strain curves of the material, discretizing the sections into many fiber elements at the sectional level and integration points (IP) along the element length. The approach is very popular in earthquake engineering and the open-source software, OpenSees, provides a very wide, accessible, and independent platform for the users. Figure 1 illustrates the comparison of the plasticity types.

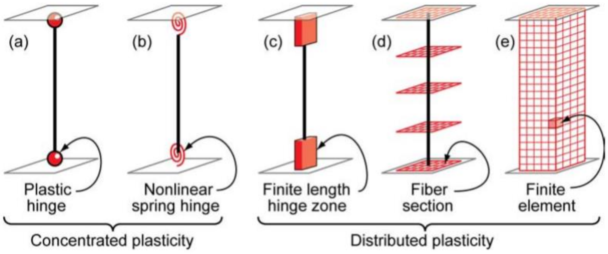


Figure 1. Various of the type of plasticity in an element [12]

This study examines the comparison of force-based elements and displacement-based elements in columns using nonlinear fiber elements. Within the scope of the study, the OpenSees program is employed for columns selected from the PEER (Structural Performance Database) site. The aim is to compare the employment of the FB element and DB elements in RC columns in terms of the number of elements and integration points, to simulate the global behaviour of the columns numerically, and to optimize the parameters that affect the results.

2. Selection of Columns and Their Properties

The PEER Database is utilized while selecting the experimental test in this study [13]. During the selection process, the failure type of the column is the key parameter and the columns with flexural failure are selected. Table 2 shows the column selection window of the PEER Database summarizes the material and geometrical properties of the selected columns for the paper. The material and geometrical properties of the columns are discussed in detail below:

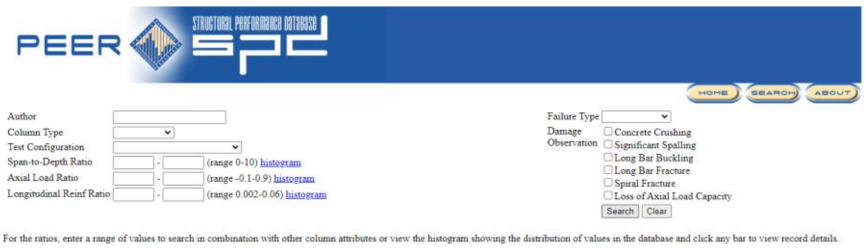


Figure 2: The selection window of the PEER Database [13]

2.1 Bayrak_AS-6HT Column

(Bayrak,1996), presents the results of an ongoing research program aimed at examining concrete wrapping with lateral reinforcement. The present study is concerned with the experimental behaviour of high strength concrete (HSC) and ultra-high strength concrete (UHSC) column behaviour. In experimental program, specimen consisted of a 0.305 m x 0.305 m x 1.473 m column and they applied 4360 kN axial load [14].

2.2. Matamoros_C10-05S Column

(Matamoros,1999), was carried out to investigate the behaviour of columns made with high-strength concrete subjected to shear reversals. The main variables of the experimental study were axial load and concrete strength. Column dimensions and the amount of transverse reinforcement did not vary between specimens. The dimensions of the samples are 0.203 m x 0.203 m x 0.610 m. The axial load we used in our study is 142 kN [15].

2.3. Ohno_L2 Column

(Ohno,1984), have proposed that the energy absorption capacity of structures is well-suited index for seismic safety. They investigate the energy absorption capacity of structures quantitatively. Five reinforced concrete columns were tested under four types of repeated loading. The dimensions of the samples are 0.4 m x 0.4 m x 1.6 m. The axial load we used in our study is 127 kN [16].

2.4. Saatcioglu_BG8 Column

(Saatcioglu,1999) Experimental research was conducted to investigate structural performance of reinforced concrete columns confined with welded grids. Ten column specimens were designed, constructed and tested. The dimensions of the samples are 0.35 m x 0.35 m x 1.645 m. The axial load we used in our study is 961 kN [17].

2.5. Saatcioglu_U7 Column

(Saatcioglu,1989) In this study, the effect of reinforced concrete columns on seismic loading was investigated. Full-scale columns were tested under slowly applied lateral load reversals. Both unidirectional and bidirectional loadings were included. The dimensions of the samples are 0.35 m x 0.35 m x 1 m. The axial load we used in our study is 600 kN [18].

2.6. Tanaka No. 5 Column

(Tanaka,1990) Basically, in his thesis, he studied the effect of lateral limiting reinforcement on the ductile behaviour of reinforced concrete columns. The dimensions of the samples are 0.55 m x 0.55 m x 1.65 m. The axial load we used in our study is 968 kN [19].

2.7. Rodrigues Column

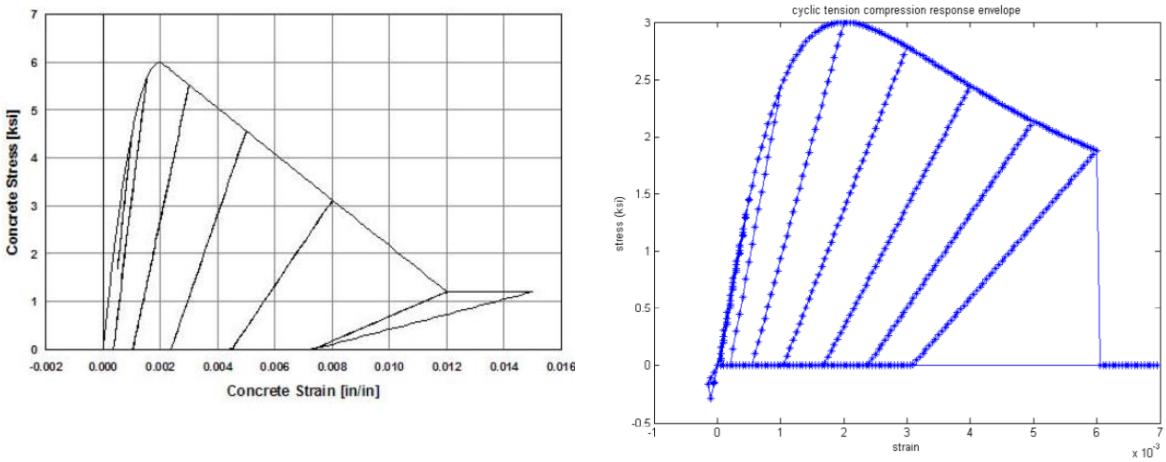
Rodrigues in his thesis, focuses on the assessment of the structural response of RC columns under bidirectional horizontal loads in three main streamlines. The dimensions of the samples are 0.2 m x 0.4 m x 1.7 m. The axial load we used in our study is 170 kN [20].

Table 2. Material and sectional properties of the selected columns

Specimen	Concrete Strength (MPa)	Stirrup Yield Stress (MPa)	Stirrup Strength (MPa)	Longitudinal Rebar Yield Stress (MPa)	Longitudinal Rebar Bar Ratio (%)	Axial Load (kN)
Bayrak_AS-6HT	101.9	463	648	454	2.58	4360
Matamoros_C10-05S	69.6	406.8	639.5	586.1	1.93	142
Ohno_L2	24.8	325	0	362	1.42	127
Saatcioglu_BG8	34	580	720	455.6	2.93	961
Saatcioglu_U7	39	425	0	437	3.21	600
Tanaka No.5	32	325	429	511	1.25	968
Rodrigues	48.4	4	500	432	0.85	170

3. Modeling on OpenSees

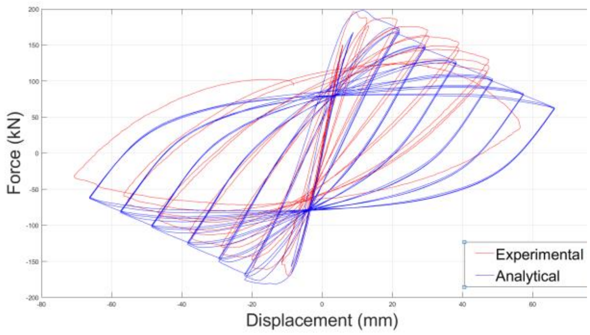
The given material properties by the experimental results for each column are used in the numerical models. The concrete elements are modelled using Concrete04 for confined concrete and Concrete01 for unconfined concrete, representing the concrete cover. Figure 3 displays the stress-strain relation for the concrete material. Reinforcing steel is utilized from the software library for the longitudinal reinforcing bar. The buckling of reinforcing bars is considered, and the unsupported length for local buckling is computed for each column (S). Calabrese et al. emphasized the numerical issues on the distributed plasticity and enlightened physical regularization techniques to eliminate them for the objective and non-objective responses [21]. Those physical regularization techniques are employed on the numerical models. For FB elements, the number of IP is selected using an aspect in which the plastic hinge length over the height of the column provides a good approximation. The plastic hinge length is assumed being equal to the greatest section size of the column. [9] And for DB elements, the same perspective is implied to the height of the first element (employed two elements for all cases with 2 IP in each case).



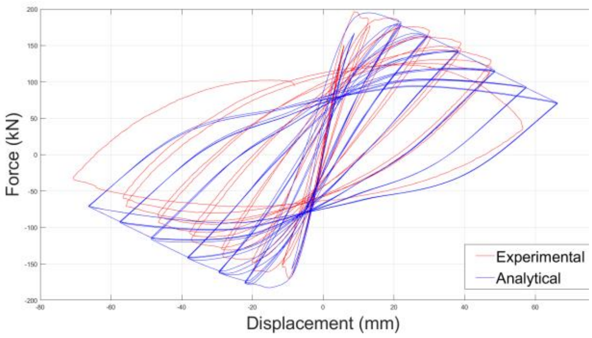
(a). Concrete01 Stress – Strain Curve (b). Concrete04 Stress – Strain Curve
Figure 3: The selected models for confined and unconfined concrete in the models [22]

4. Results

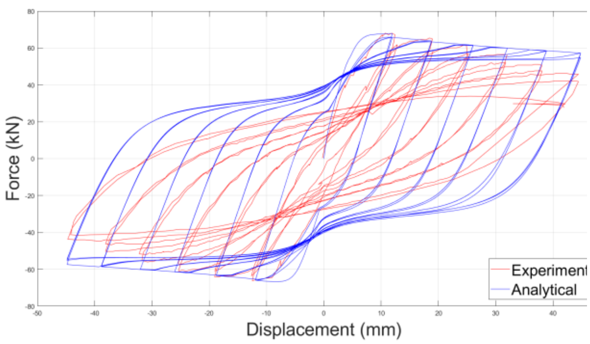
Figure 4 compares the results obtained for each selected column using different fiber element types. In general, both element types provide good agreement with the experimental results. The displacement-based element provides a stiffer response, and the convergence problem can be observed, especially among the models with a high axial load level. The force-based element may have some difficulties regarding the convergence problem, and the divergence may occur at an early stage of the analysis; however, there is a greater agreement in terms of the maximum base shear between the experimental results. Pinching phenomena were able to capture through the numerical models in both element types because buckling is considered using reinforcing steel element for steel, and local buckling length is computed. The hardening and softening behaviour of the columns (which is related to the axial load level) can be simulated well. The Bayrak AS-6HT column shows great agreements in both element types, while the FB elements show greater match specifically along with the softening range. The Matamoros column with the FB element is able to simulate the maximum and elastic zone better. Meanwhile, the model with the DB element shows some dispersions through the softening zone. The pinching behaviour is captured better on the model with the FB element. The Ohno column model with the FB element displays a very good agreement on the softening range and is able to capture the ultimate displacement. Both models of the Saatcioglu BG8 column are not able to capture the pinching, but overall, they do have good agreement with the two models. The models for the Saatcioglu U7 column captures pinching very well. However, the model with the FB element shows lower and the model with the DB element higher global response than the experimental results. For the Tanaka column, the model with the FB element illustrates a better agreement regarding maximum response, softening zone, and pinching. The results are compared in detail in Table 3.



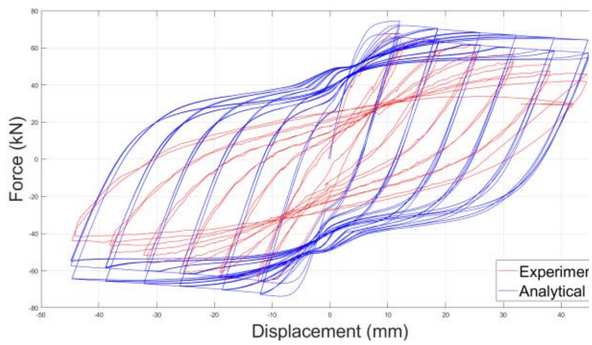
a. Bayrak AS-6HT FB



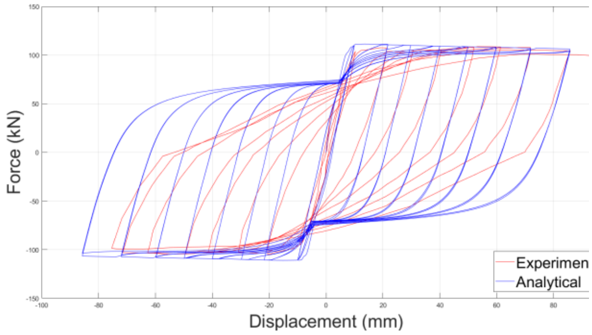
b. Bayrak AS-6HT DB



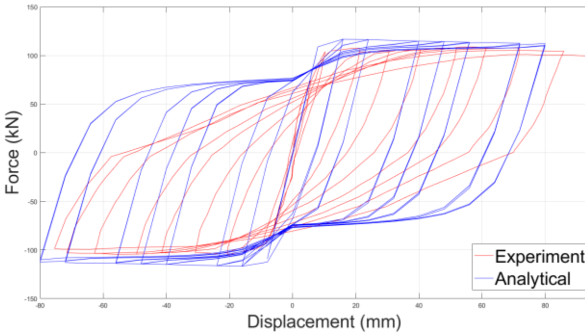
c. Matamoros FB



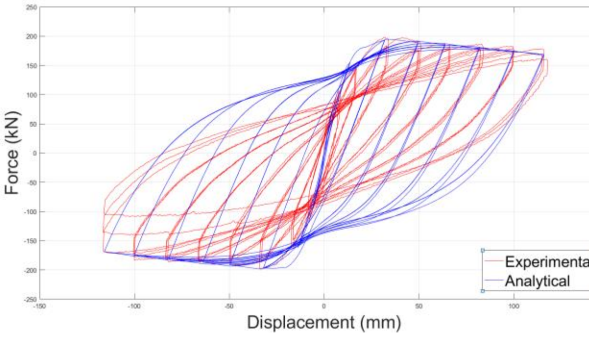
d. Matamoros DB



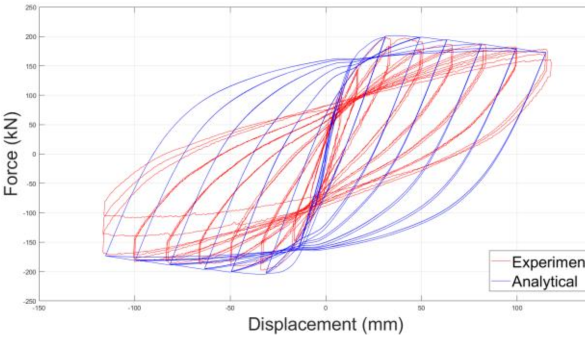
e. Ohno FB



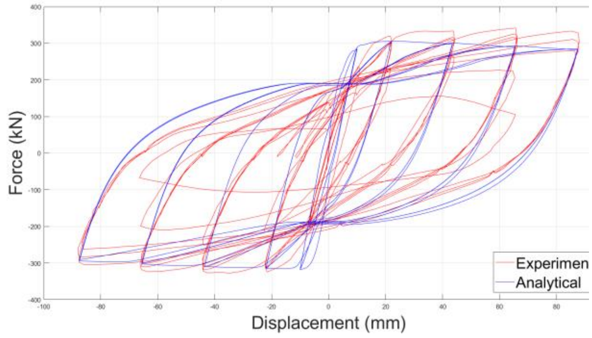
f. Ohno DB



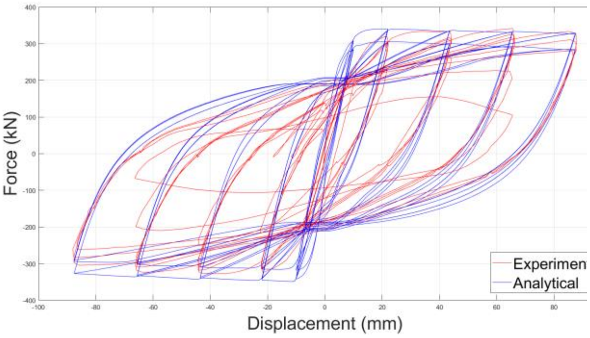
g. Saatcioglu BG8 FB



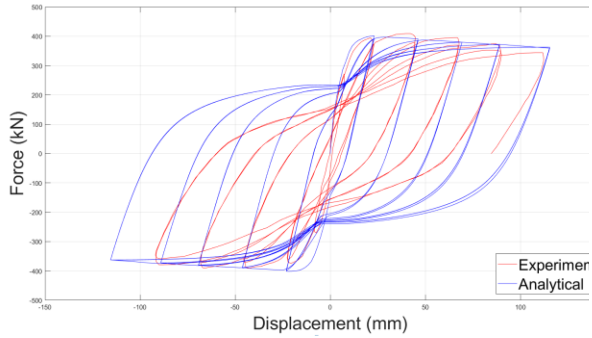
h. Saatcioglu BG8 DB



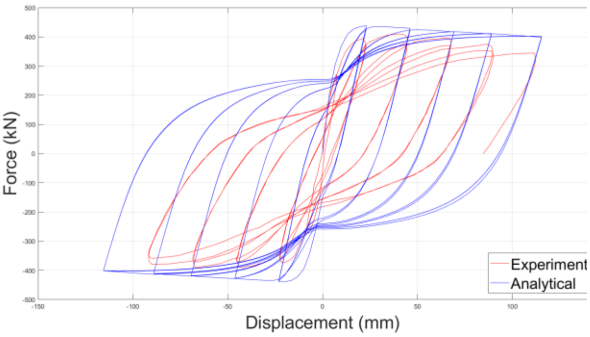
i. Saatcioglu U7 FB



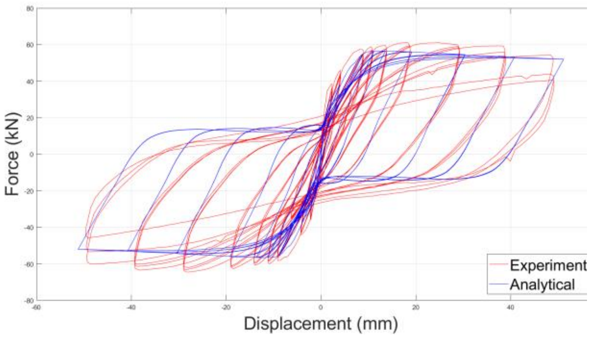
j. Saatcioglu U7 DB



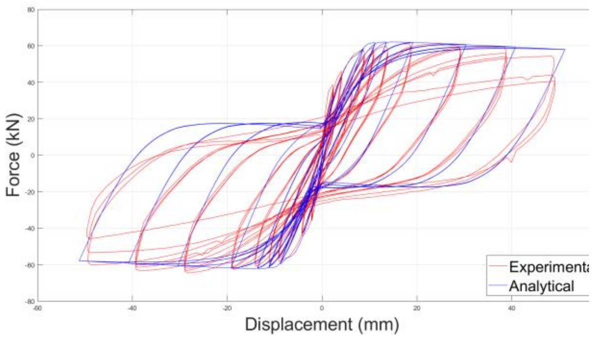
k. Tanaka FB



l. Tanaka DB



m. Rodrigues FB



n. Rodrigues DB

Figure 4: (a-n) Comparison of the global responses for each column using FB and DB elements

5. Summary and Conclusion

This paper simulates seven columns available in the literature using numerical models via the OpenSees software and figuring out the parameters that influence the global responses of the columns. Two types of the element, FB and DB elements, are utilized, and physical regularization techniques are employed while selecting IP numbers and the number of elements. Table 3 provides the details in results obtained from the numerical models and compares them with the experimental results. In the global sense, very good agreements are achieved using both element types. However, the DB elements provided stiffer responses before the maximum point. The FB element, however, showed slightly better agreements, specifically capturing the softening behaviour. The results of the column of Bayrak illustrate a good agreement in FB and DB models. Both could capture the initial stiffness, the maximum response, pinching, and softening slope. The maximum response obtained at the test is 196.55 kN, and the FB and DB numerical models achieved 198.49 kN (+0.99% error) and 194.95 kN (-0.81% error), respectively. The experimental result of the Matamoros column is 68.05 kN, and the results gathered from the FB element models are 67.84 kN (-0.3% error), and from the DB element model is 74.331kN (+9.22 % error). The Ohno models show agreeable results as well. In the FB model, global behaviour is captured slightly better because the agreement with the softening behaviour and pinching are more suitable. The maximum response obtained at the test is 108.7 kN, and the FB and DB numerical models achieved 11.35 kN (+0.99% error) and 116.787 kN (-0.81% error), respectively. The results from Saatcioglu BG8 models from experimental, FB, and DB models are 198.48 kN, 198.28 kN (0.1% error), and 205.009 kN (3.28% error), respectively. The global responses match in good agreement with the experimental result. The maximum response of the Saatcioglu U7 column obtained at the test is 341.80 kN, and the FB and DB numerical models achieved 317.89kN (-6.99% error) and 348.672 kN (+2.01 % error), respectively. The results of the column of Tanaka illustrate a fair agreement in FB and DB models. Both could capture the initial stiffness, the maximum response, pinching, and softening slope. The maximum response obtained at the test is 409.20 kN, and the FB and DB numerical models achieved 401.58 kN (-1.86 % error) and 438.962 kN (+7.27 % error), respectively. The experimental response of the Rodrigues column is 68.4 kN. The obtained results from the FB and DB models are 66.67 kN (-2.53 % error) and 72.56 kN (+ 6.08 % error), respectively. In these models, pinching has been captured well.

Since the DB element demonstrates stiffer and approximate solutions, initial stiffness in all the columns shows stiffer response, and the results with the FB element display smaller errors. The FB element provides an exact solution for linear and nonlinear elements. Exceptionally, the Saatcioglu_U7 column result with the DB element reveals better agreement. One reason could be standing as a short column, in which the triple size of the section is the height of the column.

Meanwhile, assuming the plastic hinge length as the greater size of the section provides a very satisfying response in the models in this study. It could be concluded that the physical regularization techniques are quite effective in reaching out the global match between experimental and numerical results considering the limited number of IPs and elements are employed in the models.

Table 3. Comparison of Experimental and Analytical Results

	Experimental Tests						Results using FB Elements		Results using DB Elements	
Specimen	**Width (m)**	**Depth (m)**	**Length (m)**	**Axial Load Ratio (%)**	**S Hoop Spacing (mm)**	**Maximum Base Shear (kN)**	**Number of Integration Points FB**	**Maximum Base Shear (kN)**	**Length of the first element (m)**	**Maximum Base Shear (kN)**
Bayrak_AS-6HT	0.305	0.305	1.842	0.46	76	196.55	6.03≈**6**	198.49	0.305	194.952
Matamoros_C10-05S	0.203	0.203	0.61	0.05	76.2	68.05	3.00≈**3**	67.84	0.203	74.331
Ohno_L2	0.4	0.4	1.6	0.03	100	108.70	4.00≈**4**	111.35	0.4	116.787
Saatcioglu_BG8	0.35	0.35	1.645	0.23	76	198.48	4.70≈**5**	198.28	0.35	205.009
Saatcioglu_U7	0.35	0.35	1.00	0.12	65	341.80	2.85≈**3**	317.89	0.35	348.672
Tanaka and Park No.5	0.55	0.55	1.65	0.1	110	409.20	3≈**3**	401.58	0.55	438.962
Rodrigues	0.2	0.4	1.70	0.04	60	68.4	4.25≈**4**	67.77	0.4	73.79

Author Contribution

T.T. and A.F.C designed the concept of the study. A.F.C. performed the numerical simulation. T.T. and A.F.C. wrote the manuscript.

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