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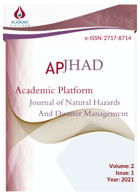

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Flash Flood struck Dhauliganga valley on February 7, 2021: A Case study of Chamoli district of Uttarakhand Himalaya in India

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Abstract

Combining effects of prolonged rock fall, glacier avalanche, multiple damming of streams, rapid erosion of slope materials and sudden rise in temperature witnessed a flash flood situation on 7 February, 2021. Aftermath of initial incidence which was occurred in the morning 1015 hours at upper reaches of Raunthi Gadhera, within 30 minutes Rishiganga, Dhauliganga and Alaknanda rivers swelled enormously. Unprecedented discharge of the same washed off functional Rishiganga hydroelectric project of 13.2 MW capacity on Rishiganga near Rini while badly damaged under construction hydropower project of 520 MW of National Thermal Power Corporation at Tapoban on Dhauliganga river. Except for, 5 pedestrian bridges in various places over Dhauliganga river along with one motorable RCC bridge over Rishiganga at Rini leading to Joshimath - Malari State Highway were swept away in flash flood wherein disrupted the connectivity along with other supply of 13 villages. This caused heavy damage to life and property, particularly in these hydropower project sites. As many as 204 persons went missing, of these bodies of 77 persons could be recovered along with 12 persons injured and 184 farm animals were lost in this incidence. The aim of the present research is to examine the possible causes of the rock fall and flash flood together with their destructive effects. This work also focuses on present risk scenario and suggestions for disaster risk reduction within the affected region.

Key words: Changes in river morphology; Damages; Flash flood; Higher Himalaya; Losses; Multiple damming; Rock fall

1. Introduction

The fragility of Higher Himalayan terrain because of freeze-thaw actions, Thrusts/Faults and earthquakes together with high relief, narrow valley, steep slopes, intense rains and increase in temperature makes this region highly prone to a number of hazards like avalanches, rock falls, debris flows, floods and flash floods etc. Because of change in weather regime, both the magnitude and frequency of flash floods and floods have increased in the same region. These events are significant both in terms of damage to infrastructure, property, and especially in

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terms of human lives [1]. Furthermore, developmental activities trigger the flood and increase the flood damage in flood plains of hydrological watersheds [2].

Cloudbursts or heavy localized precipitation and ensuring flash floods and landslides are the major concern of the region [3] and these are however often attributed to climate change [4]. But the effects of global warming, and the related changes in climate, on geo-hydrological hazards like floods, landslides and droughts remain difficult to determine, and to predict [5]. Hence, there is dire need to understand the climatic variability to overcome its harmful effects on geo-environment. Between years 1970 to 2019, total of 50 known cases of cloudbursts were recorded in Uttarakhand region, of which alone 12 events have been observed in Chamoli district killing around 300 persons and damaging numbers of property and infrastructure in these incidences [6].

In June 2013, five districts namely Chamoli, Rudraprayag, Uttarkashi, Bageshwar and Pithoragarh witnessed massive devastation due to cloudburst/heavy rainfall and associated flash floods. More than 4000 persons went missing in these incidences that caused enormous loss of infrastructure and property [7]. Because of the same, major geomorphic changes have been introduced at Kedarnath in the Mandakini valley of Rudraprayag district [8] whereas in Lambagar, Govindghat, Bhuindar and Pulna in Alaknanda valley and Tharali and Narayanbagar in Pinder valley of Chamoli district [9].

Similarly, in July 2016 the Bastari village affected by cloudburst disaster incidence are traditional habitations where people had been living happily for ages. Except for heavy rains caused landslide incidences and damages in the area around Didihat and Naulra villages. As many as 22 human lives were lost in these incidences [10].

The hilly region of Uttarakhand experienced landslides and avalanches wherein the channel of streams were blocked caused extensive flooding downstream. Flooded water of the same brought down huge amount of sediments caused aggradation in many places along the course of streams. Between the years 1857 to 2018, total of 24 events of damming of streams were recorded in the same region of which alone 12 events have been observed in the Chamoli district [11]. It is evident that the damming of streams were observed due to different geomorphological and lithotectonic causes wherein some important are (i) confluence of tributaries; (2) narrow valley; (iii) Thrust/Fault and folded strata; and (iv) physical and chemical weathering in rocks. Whatever the causes of damming of streams in the region but it was observed that most of the dam breached during the monsoon season. In the year 1893, the region experienced a massive rock fall in Birahi valley which blocked the course of Birahiganga and formed a lake named as Gohna lake. Partial breach of this lake in year 1894 and ultimate breach in year 1970 (after 76 years long period) during monsoon caused enormous flooding downstream. Similarly, in the year 1968, landslide near Rini blocked Rishiganga, created a 40 m high dam and breached in year 1970 (after 2 years) during monsoon causing extensive damages in downstream.

The incidence of prolonged rock falls and slumping of rock-masses even during dry seasons witnessed in the Kali and Gori valleys in Pithoragarh district, imply continuing movement at present on some of the faults of the MCT zone. This is further borne out by occurrence of earthquakes all along the belt, just south of the Great Himalayan axis [12]. During non-monsoonal period, the region has witnessed Varunavat landslide in Uttarkashi district occurred on September 23, 2003 while Ramolsari landslide in Tehri district on March 30, 2005 [13]. There however exist no record of flash floods during the non-monsoonal period.

The state of Uttarakhand falls in Zone IV and Zone V of Earthquake Zonation Map of India [14]. However, the present devastated Chamoli district lies in Zone V. In the recent decades, the state has witnessed two major earthquakes one of 1991 Uttarkashi (6.6Mw) and another of 1999 Chamoli (6.8Mw) wherein respectively 768 and 106 persons lost their lives [6]. These earthquakes occurred along the MCT, which reactivated the local faults [15].

A massive rock fall along with hanging glacier which triggered in the catchment of Raunthi Gadhera, a tributary of Rishiganga on February 7, 2021 in Chamoli district of Indian subcontinent of Uttarakhand. Subsequent blockade of the course of the same and sudden breach of landslide dam and sequential damming (at confluence of Raunthi Gadhera with Rishiganga, North of Murunna and at confluence of Rishiganga with Dhauliganga river at Rini) caused massive damages and destructions in the Rishiganga, Dhauliganga and Alaknanda rivers, particularly in the area around Rini and Tapoban. It was surprising to everyone that this flash flood occurred during the winter months when the discharge of the glacier fed rivers is minimal.

According to some researchers energy generated by mass movement and as also available temperature data indicates that sudden rise in temperature facilitated fast melting of freshly accumulated snow and ice resulting in sudden breach of dam build by landslide mass in the form of flash flood. This inflicted heavy loss of life, property and infrastructure in the downstream. Because of unapproachable event site, nobody has not known the actual ground truth and that is why, it is a cause of concern for the government, meteorologists, glaciologists, geologists and other researchers around the Worldwide. In order to effort made in the area proximity to incidence site, to evaluate the causes of rock fall and flash flood along with changes in river morphology and suggested measures for disaster risk reduction in the affected areas.

2. Materials and Methods

2.1. Study area

Present study covers Dhauliganga valley that lies in Higher Himalayan region of three tectonic blocks; (i) Main Central Thrust (MCT); (ii) Vaikrita Thrust (VT), and (iii) Trans-Himadri Fault/Malari Fault and is falls in toposheet numbers 53N/10, 53N/11, 53N/13, 53N/14 and 53N/15 (Fig. 1). A massive rock fall along with glacier avalanche took place at an elevation of 3800 m asl to 3600 m asl at the base of Nanda Ghungti (6309 m) which is located southeast of Rini village on the left bank of Raunthi Gadhera, a major tributary of Rishiganga river in this region. Joshimath town can be approached by Rishikesh-Badrinath National Highway (NH 58) and is at a distance of 257 km from Rishikesh. Rishikesh is the nearest rail head while Jolly Grant is the airport. Besides, nearest airport is at Gauchar in the area.

The flash flood affected area can be approached by Joshimath – Malari state highway. The devastated area of Rini village is situated around 22 km upstream of Joshimath town where has confluence of Dhauliganga river with Rishiganga. There was an operational hydropower project of 13.2 MW capacity on the left bank of Rishiganga upstream of Rini. Another devastated area of Tapoban is situated around 15 km upstream of Joshimath town where barrage site of a hydroelectric project of 520 MW capacity is being constructed on Dhauliganga river by National Thermal Power Corporation (NTPC).

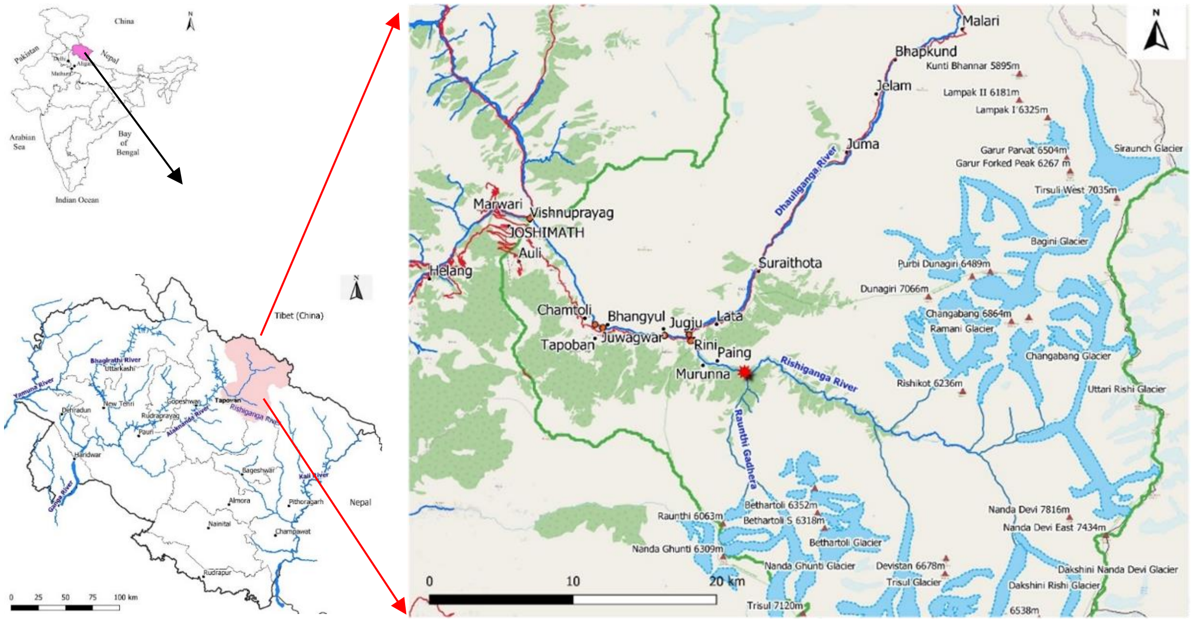

Figure 1: Location map of devastated area

2.2. Data set and Tools

With the help of Survey of India toposheet numbers 53N/10, 53N/11, 53N/13, 53N/14 and 53N/15 on the scale of 1:50000 and handset GPS (Global Positioning System) preliminary geological assessments of the devastating flash flood in the Dhauliganga valley in Chamoli district, Uttarakhand was carried out between 19 and 28 February, 2021. Traverses were taken around the devastated areas as Rini (N 30°29'15.34" E 79°41'34.91") and Tapoban (N 30°29'29.76" E 79°37'49.68") to examine the geological setup and to investigate the cause of flash flood. Survey of India toposheets have also been utilize for preparation of location and other appropriate maps using Geographical Information System (GIS) software (Arc View 9.3). On the basis of information gathered, critical locations were identified for priority assessment. Attempts were also made to assess the causes of rock fall, devastating flash flood, present risk scenario and suggested measures for the safety of downstream population from the future threat.

3. Geological setting

The area of investigation exposes Higher Himalayan Central Crystalline Group of rocks which are thrusted over the Lesser Himalayan Garhwal Group of rocks, along a Northerly dipping Main Central Thrust (MCT) passing near Helang in Alaknanda valley. To the North of MCT, Helang Formation represents low to medium-grade rocks of greenschist facies whereas Joshimath, Suraithota and Bhapkund Formations of Vaikrita Group constitute medium to high grade rocks of amphibolite facies. These two metamorphic facies rocks are separated by Northeasterly dipping Vaikrita Thrust (VT) tracing in the proximity of Rini village in Dhauliganga valley. Another major plane of dislocation named as Trans-Himadri Fault/Malari Fault marked in Dhauliganga valley near Malari separates the Martoli Formation of Tethyan Himalayan Sequence from the Central Crystallines. Details of lithostratigraphy are given in Table 1.

Table 1: Lithostratigraphy of the area [16-19].

<table>
<tr><td rowspan="2">Tethyan Himalayan Sequence (THS)</td><td>Martoli Formation</td><td>Greyish green slate and quartzite</td></tr>
<tr><td colspan="2">Trans-Himadri Fault (T-HF)/Malari Fault (MF)</td></tr>
<tr><td rowspan="6">Higher Himalayan Crystalline Zone (HHCZ)</td><td>Bhapkund Formation</td><td>Sillimanite-garnet-biotite psammitic gneiss/ schist, small tourmaline-rich leucogranite lenses/ dykes and Migmatite, Malari leucogranite</td></tr>
<tr><td>Suraithota Formation</td><td>Kyanite-garnet-biotite schist / psammitic gneiss and quartzites with thin amphibolite intercalations</td></tr>
<tr><td>Joshimath Formation</td><td>Garnet-biotite-muscovite schist and psammitic/pelitic gneiss</td></tr>
<tr><td colspan="2">Vaikrita Thrust (VT)</td></tr>
<tr><td>Helang Foramtion</td><td>Ganet-mica schist, augen gneisses and amphibolites, quartzite</td></tr>
<tr><td colspan="2">Main Central Thrust (MCT)</td></tr>
<tr><td>Lesser Himalayan Sedimentary Zone (LHSZ)</td><td colspan="2">Garhwal Group
(Meta-sedimentary and metamorphic rocks)</td></tr>
</table>

The affected area belongs to rocks of Higher Himalayan Vaikrita Group. Exposures of garnet-mica schists, gneisses, amphibolites and quartzites of Joshimath Formation are observed in the area around the Rini as well as on the left bank of Rishiganga upstream of Rini. At the confluence of Rishiganga with Raunthi Gadhera, mostly exposures of quartzites of Suraithota Formation are observed on the right bank of Raunthi Gadhera as well as both the banks of Rishiganga. These rocks are medium to course grained, greyish coloured, medium to thickly foliated and slightly to moderately weathered in nature. Rocks exposed in the area are generally observed to strike NW–SE with moderate dips towards NE. Other two prominent joints were observed to dip towards W and NW at steep angles (70º / 270º and 70°/310°). Except for, vertical joints was observed to strike NE–SW (90°/70°).

4. Geomorphology and Physiography

Flash flood of February 7, 2021 took place in the North flowing Raunthi Gadhera that originates from the glaciers of Nanda Ghungti (6309 m). It has confluence with Rishiganga to the East of Paing and Murunna villages and maintains a tectonically controlled NW-SE course that originates from the glaciers of Nanda Devi massif. Just upstream of confluence of Rishiganga with Raunthi Gadhera area, the Raunthi Gadhera flows along the strike of exposed quartzites whereas Rishiganga flows across the strike of the same rocks. To the downstream of confluence of the same, almost Rishiganga flows along the strike of in-situ rocks. It meets with Southwest flowing Dhauliganga river at Rini village that originates in the proximity of Niti pass. From Rini to Tapoban Dhauliganga river maintains a tectonically controlled E-W course and thereafter flows from NW-SE to meet Alaknanda river at Vishnuprayag.

Physiographically, the Rishiganga valley represents high rugged mountainous topography with high relative relief that are intervened by narrow valleys. To the South of Rini village, the valley is relatively narrow till Tapoban. Around 2 km upstream of Tapoban a hot water spring is located on the left bank of Dhauliganga river. Relatively wide valley in Tapoban thereafter narrow valley is observed till Vishnuprayag. Some of the high ridges and peaks of the Rishiganga are Hanuman (6,070 m), Trisul (7,045 m), Sunderdhunga Khal (6,350 m), Nanda Devi (7817 m) are the well-known peak in the region. The relief in the area is highly variable ranging from 1450 m asl at Vishnuprayag to 7817 m asl at Nanda Devi peak. To the downstream of villages Rini and Jugju, villages like Saldhar, Chanchri, Suhhain, Ringi and Tapoban are situated on the left bank of Dhauliganga river while villages like Juwagwar and Bhangyul are situated on the right bank. The hills on the right bank of the Dhauliganga river are observed to form high rocky surfaces in the same region.

4.1. Changes in river morphology

The devastating flash flood of February 7, 2021 made significant changes in the river morphology around the confluence of Raunthi Gadhera and Rishiganga. Between 9 and 11 February, 2021 the course of Rishiganga stream was permanently blocked by the debris brought down by the Raunthi Gadhera after breaching of landslide dam. Flooded water saturated debris with boulders and ice blocks of Raunthi Gadhera directly hit the valley wall which back flowed upstream along the Rishiganga dumped a huge sediments and created an artificial lake (Fig. 2a). Based on satellite imageries first by Uttarakhand Space Application Centre (USAC) on February 9, 2021 and later by Indian Institute of Remote Sensing (IIRS) were provided the information of a lake formed along the course of Rishiganga. The same was confirmed by the reconnaissance teams on February 11, 2021. As observed on February 11, 2021 water was not draining out of this lake. The Rishiganga was curved out channel from the center of the lake through which water is continuously draining out on February 12, 2021.

The lake area can be approached from both Paing and Murunna villages which are situated on the right and left bank of Rishiganga respectively. It is placed along Rishiganga about 500 m upstream of the confluence of Raunthi Gadhera with Rishiganga at an altitude of 2389 m asl having embankment of approximately 100 m and visually estimated linear length of around 500 m (Fig. 2a). It was observed that both the sides exposures of thickly to medium foliated, moderately jointed and slightly to moderately weathered quartzites that of Suraithota Formation of Vaikrita Group of rocks having with vertical cliffs. The muddy debris is to be observed on the both banks of Raunthi Gadhera whereas the Rishiganga was completely covered with huge muddy debris till lake.

It was also observed that the Rishiganga curved out around 8 m wide channel by the erosion of the natural embankment in the center portion till dated February 19, 2021. As directed to personnel of ITBP and SDRF, physically widen the channel and cleared of obstructions of logs (Fig. 2b). The channel was thus widened up to 20 m between February 22 and March 2, 2021 to ensure proper draining out water from the lake. Just upstream to confluence of Rishiganga with Raunthi Gadhera, huge slope materials was eroded on the left bank of Raunthi Gadhera while thick pile of sediments was deposited on the right bank of the same because of the flooding (Fig. 2c). This sediments comprising of a mixure of ice blocks, rock fragments, morainic material and boulders of quartzite, granitic gneiss and mica schist with silty-clayey matrix (Fig. 2d).

To the downstream of confluence, slope materials which was laid over valley side dipping rocks on the left bank of Rishiganga was badly eroded till North of Murunna village and pedestrian route was also completely washed away which was located on the same materials (Fig. 2e). Thereafter, debris cone and old landslide mass were also badly eroded on the right bank of Rishiganga up to confluence of Rishiganga with Dhauliganga at Rini (Fig. 2f).

Figure 2: Changes in river morphology on the aftermath of flash flood; (a) lake formation over Rishiganga; (b) physically widen the channel and cleared of obstructions of logs; (c) eroded left bank while aggradation on the right bank of Raunthi Gadhera; (d) ice block observed in the transported debris materials; (e) badly eroded slope materials on the left bank of Rishiganga river; and (f) eroded debris cone and old landslide mass on the right bank of Rishiganga at Rini

A huge amount of sediments of fluvio-glacial, slide mass and eroded slopes were deposited all along the course of Rishiganga, Dhauliganga and Alaknanda by ensuing floodwaters. As recorded by the gauging station of Central Water Commission (CWC) at Marwari, the discharge of Alaknanda river at 1100 hrs on February 7, 2021 reached 1,670 cumecs as against normal discharge of around 41 cumecs at 1030 hrs. CWC was also assessed that increase of 3.09 m in the river bed level of the Alaknanda river at Marwari on February 10, 2021. The sediment thickness is observed to reach around 12 m at the under construction barrage site at Tapoban whereas around 2 – 4 m in the area around Rini.

4.2. Losses and damages

As many as 204 persons went missing while 12 persons injured in the flash flood incidence and except for 9 local inhabitants of these 5 of Rini, 2 of Tapoban and 2 of Ringi villages and 2 Police personnel others were from amongst those engaged by the hydropower projects that were devastated in the incidence. Out of total, 77 bodies could be recovered while 184 farm animals were lost in this incidence (Data source: State Emergency Operations Centre (SEOC), Uttarakhand). According to Hydroelectric project Authority, about 30-35 persons were reportedly working in a tunnel that was chocked with silt and debris transporting by flooded water of Dhauliganga river. Total of 6 bridges were swept away by the floodwaters of which 5 pedestrian bridges which were located on the Dhauliganga river at Rini, Bhangyul, Juwagwad, Tapoban and Vishnuprayag while one motorable RCC bridge over Rishiganga river on Joshimath – Malari State Highway at Rini in which disrupted connectivity for the residents of 13 villages (Fig. 3).

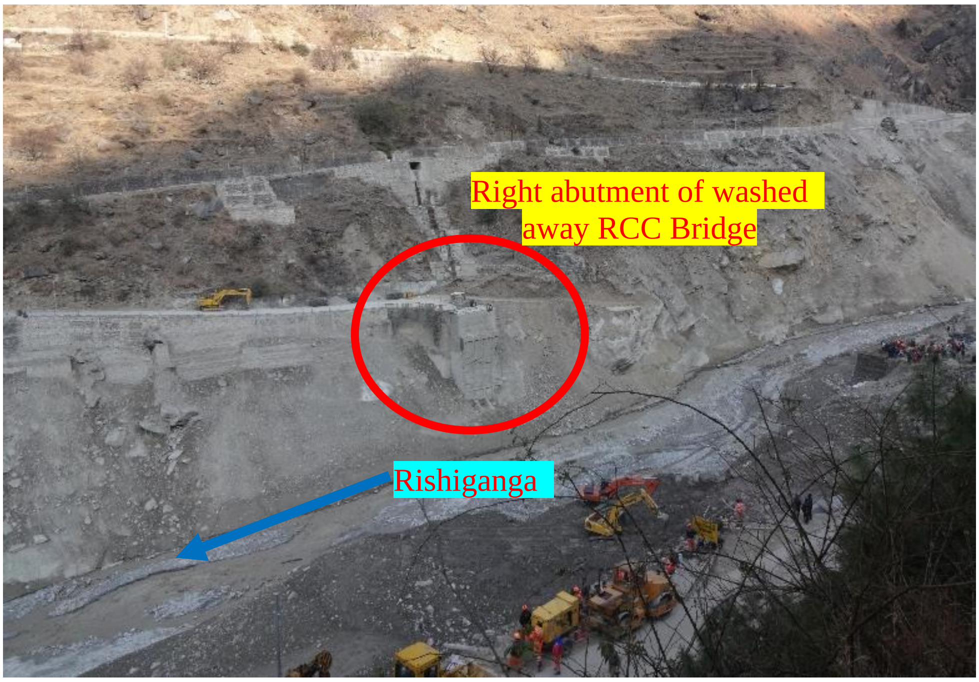

Figure 3: Washed away a motorable RCC bridge over Rishiganga river on Joshimath – Malari State Highway at Rini

The flash flood of Rishiganga resulted in swiping away of an operational hydropower project of 13.2 MW capacity on Rishiganga upstream of Rini (Fig. 4a). To the downstream, flooded water of Rishiganga and Dhauliganga river severe damage to another under construction hydropower project of 520 MW of National Thermal Power Corporation (NTPC) at Tapoban on Dhauliganga river (Fig. 4b).

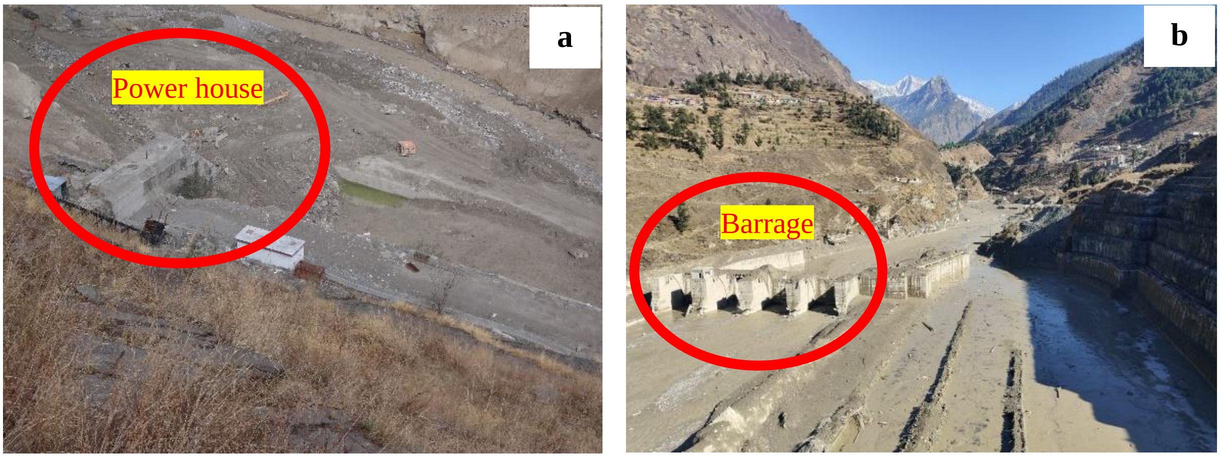

Figure 4: The devastated hydropower projects; (a) washed away power house of Rishiganga hydropower project upstream of Rini; and (b) severally damaged barrage site of Tapoban-Vishnugad hydropower project at Tapoban

4.3. Causes of rock fall and devastating flash flood

Initial observation taken from the satellite imageries of Planet Lab, energy generated by the impact of free fall of huge rock mass along with hanging glacier over almost 1,800 m was held responsible for quickly melting snow and ice available in the area and initiating a debris flow that rushed downslope [20]. This energy is converted to kinetic energy during the fall and dissipated as enough heat to melt $2.7 * 10^6$ m^3 of ice. Considering that not all the mass was converted into energy during the fall, this number is likely a lot lower. For a large co-seismic event, fluidization can also happen simply form a very large impact on present ice, which possibly happened in this case [21].

However, the region experienced precipitation on February 4 and 5, 2021 and snow fall occurred in the high altitude region of Dauliganga valley. It is evident from the Tapoban and Auli which are located at an altitudes of 2000 m asl and 2600 m asl respectively. Between 6 and 7 February, 2021 Tapoban experienced 2.8°C and 5.4°C whereas Auli 6.0°C and 9.6°C respectively in minimum and maximum temperature (Data Source: Uttarakhand State Disaster Management Authority). But it was not significant to make the situation worst, because of ice would have taken longer time than snow to melt, so this could not be the only reason for flash flood.

It is interesting to note that the Vaikrita Thrust (VT) is a major tectonic discontinuity extending to the Dhauliganga, Rishiganga and Raunthi Gadhera where the same are tectonically controlled by the VT. The Joshimath area has been intermittently sinking over a long belt for quite many decades owing to the activeness of the Vaikrita Thrust that passes by [12]. VT is separating the low-medium grade Helang Formation from the overlying medium-high grade Joshimath and Suraithota Formations in the affected area. A massive rock fall was triggered at the base of Nanda Ghungti on the left bank of Raunthi Gadhera that was observed in the close vicinity of NW-SE trending VT which activated the same. Weakening of the rocks in the affected area because of the same and this is one of the manifestations of the presence of this Thrust. Additionally, frost action and weathering could also be one of the most important factors in disintegrating the rocks in the affected area. The effect of frost action is observed to be dominant resulting in moisture and melting ice facilitate rock fall.

Field investigations carried out in the area aftermath of the devastating flash flood between 19 and 28 February, 2021 to reconstruct the sequence of events leading to Dhauliganga flash flood of February 7, 2021. Multiple temporary damming in the course of streams added the discharge and increased velocity of water saturated bouldary debris at many places. Brief description of the damming along the streams are given in the sections below.

A massive rock fall along with hanging glacier avalanche took place during the winter on February 7, 2021 when the discharge of glacier fed rivers is minimum. The affected area however witnessed precipitation on February 4 and 5, 2021 with experienced snowfall in the higher reaches. Subsequent damming and sudden breach of the same caused flash flood in the Raunthi Gadhera which gushing down wherein thick overburden covers was badly eroded on the left bank of Raunthi Gadhera. At the confluence of Raunthi Gadhera and Rishiganga (Fig. 5), flooded water saturated bouldary debris of Raunthi Gadhera directly hit the valley wall and damming the same place for a while wherein back flowed of sediment leaden discharge along the course of Rishiganga up to 500 m. Increasing hydrostatic pressure result in this temporary dam was breached and to left behind a huge sediments along with boulders and ice blocks over the course of the Rishiganga and created an artificial barrier. This completely blocked the course of Rishiganga and after filling of water left behind the same materials formed a lake. This has totally changed the river morphology of the Rishiganga valley.

Figure 5: At the confluence of Raunthi Gadhera with Rishiganga where key damming was observed

Another intermittent ponding was observed in the North of Murunna village wherein suddenly narrow valley came across. Because of erosion of a huge overburden mass on the left bank of Rishiganga, there was enough space for accumulating water. In this area the valley walls was showing water mark which was observed up to 50 m height (Fig. 6a). After adding discharge result in increasing hydrostatic pressure, sudden release of the flooded water swept away operational Rishiganga Hydroelectric project of 13.2 MW capacity along with working personals in its. At the confluence of Rishiganga and Dhauliganga river, intermittent ponding was also observed resulting into temporary ponding along the course of the Dhauliganga river up to 1.5 km (Fig. 6b). Sudden release of a huge volume of water saturated debris of both the rivers caused massive devastation in the downstream. Major destruction have however occurred at Tapoban where Tapoban-Vishnugad barrage of 520 MW was being under construction along with working personals. The intake tunnel was chocked with muddy debris where around 30 - 35 personals were working.

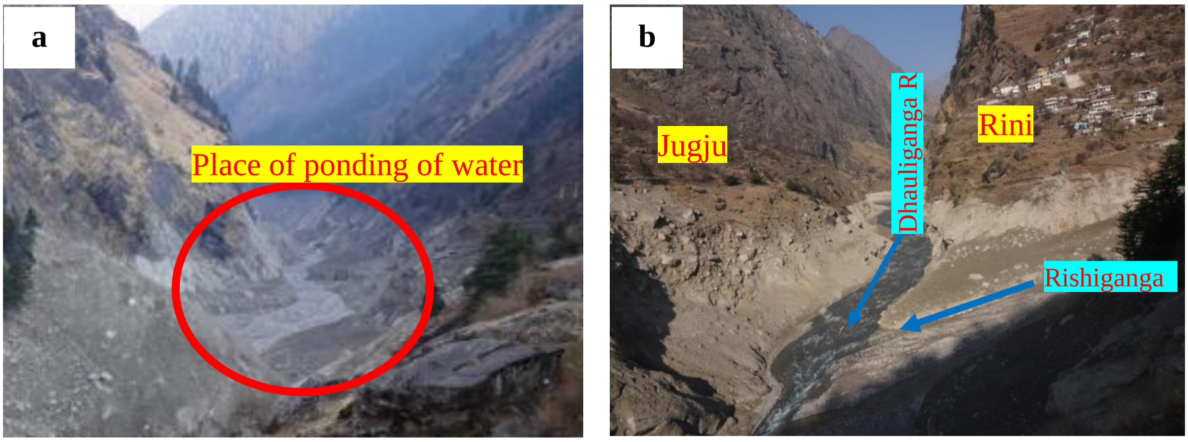

Figure 6. Intermittent ponding of streams; (a) Rishiganga to the N of Murunna village and (b) Dhauliganga river near its confluence with Rishiganga

It is important to note that just upstream to confluence of Raunthi Gadhera and Rishiganga, occurrence of lacustrine deposits that consist a layers of sand and pebbles on the right bank of Raunthi Gadhera which was indicating evidence of paleo lake in the same region. These deposits has now been mostly eroded in the flash flood of Raunthi Gadhera (Fig. 7). In the earlier, floods in the Rishiganga created a 40 m high blockade near village Rini which was formed a lake. This lake was silted up by May 1970 and eventually breached in July 1970 [11].

5. Results and discussion

Evolutionary history, geo-tectonic set up and change in weather regime in the Higher Himalayan terrain makes the region highly susceptible to a number of natural hazards. The region however falls in the high seismic zone. None occurrence of great earthquake (Mw >8) for a long period further enhances seismic risk in the region. Various anthropogenic activities for infrastructure development further aggravate the problems. Every year, the same region faces massive losses in terms of human lives, infrastructure and property due to cloudbursts, landslides, avalanches, glacial lake outburst floods (GLOFs), floods and flash floods events, particularly during monsoon season.

In the past decades, the region was hit hard by devastated flash floods in years 1970 and 2013 that caused the massive losses of human lives, property and infrastructure. In these also disrupted transport, communication, electricity and water supply facilities of the many areas for the long period. It is therefore important to plan risk assessment, better management and early warning to avoid human and other losses by these natural hazards. In case of floods and flash floods prone and inundated areas, the recent modelling technology and GIS tool should be utilized for better planning and to avoid the future threat.

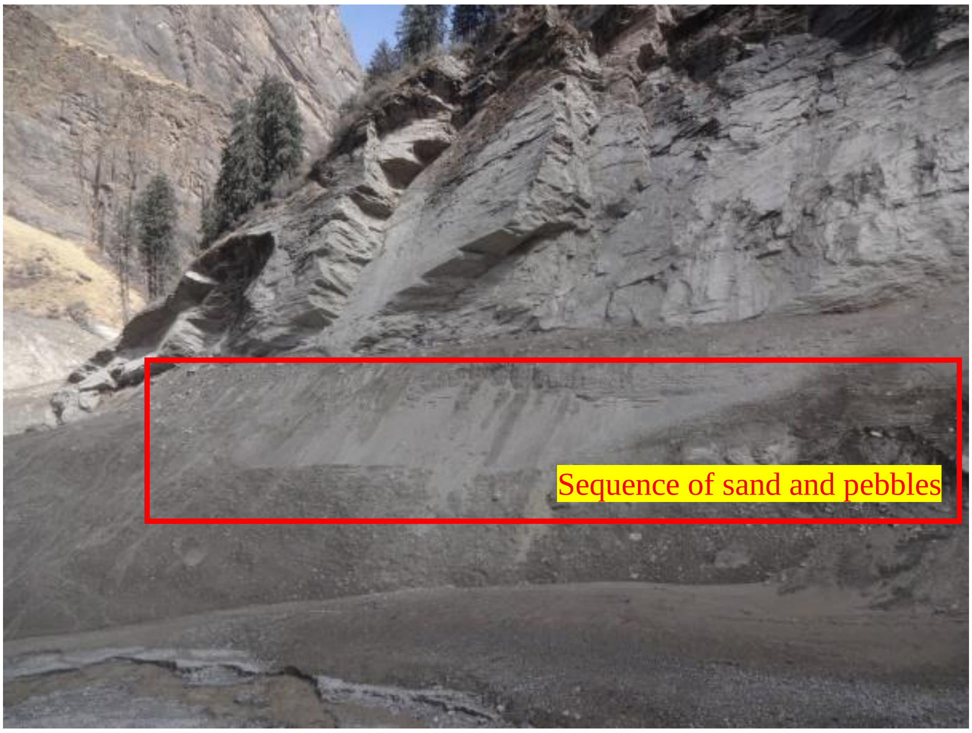

Figure 7. Lacustrine deposits on the right bank of Raunthi Gadhera near its confluence with Rishiganga

Presently, a massive rock fall along with hanging glacier that triggered on February 7, 2021 was concentrated in specific area that was associated with geomorphology and lithology. The rock fall has its origin from the base of Nanda Ghungti at an elevation of 5800 m asl having with steep rock slopes which sliding down along the foliation plane. Some researchers have suggested that during the 2016 cracks was observed at the base of Nanda Ghungti which was the initial cause of the rock fall. It was also noticed that rock fall area lies in the close proximity to major tectonic discontinuity named as Vaikrita Thrust which activated the same. Additionally, frost action and weathering could also be one of the most important factors in disintegrating the rocks. Among these are responsible for triggering rock fall in the affected area.

The rock fall along with a huge ice chunk blocked the course of Raunthi Gadhera at an altitude of 3600m asl creating a natural dam and left behind the same huge volume of water impoundment. Because of increasing hydrostatic pressure, sudden breach of the same caused initiation of flash flood. Another, key damming was observed at the confluence of Raunthi Gadhera with Rishiganga where indication of paleo lake was observed. Additionally, intermittent ponding North of Murunna village and at the confluence of Rishiganga with Dhauliganga river at Rini were also observed. Indication of previous damming of Rishiganga near Rini was documented as well. Among these added water saturated debris with boulders gushing down with fast pace ruined and washed away everything which came in their ways.

The flash flood of Rishiganga resulted in swiping away of an operational hydropower project of 13.2 MW capacity on Rishiganga upstream of Rini whereas severe damage to another under construction hydropower project of 520 MW of NTPC at Tapoban on Dhauliganga river. These caused 204 persons went missing of these 77 bodies could be recovered while 12 persons injured and 184 farm animals were lost in the flash flood incidence. Swiping away one motorable RCC bridge over Rishiganga on Joshimath – Malari State Highway at Rini along with 5 pedestrian bridges in different places along the Dhauliganga river. These resulted in inhabitants of 13 villages cut off from the road head.

The devastating flash flood of February 7, 2021 made significant changes in the river morphology around the confluence of Raunthi Gadhera and Rishiganga. Between 9 and 11 February, 2021 the course of Rishiganga stream was permanently blocked by the debris brought down by the Raunthi Gadhera after the landslide lake outburst flood (LLOF). Left behind the dumping of sediments, a huge volume of water impoundment that formed an artificial lake. Presently, this lake is draining out from the center portion but possibility of breaching of this lake in near future cannot be ruled out. As a precaution, regular monitoring of the discharge and early warning system for flood forecast should be required in the area for safety of the downstream population.

It was observed during field investigations that by and large traditional habitation in the entire affected region remained unaffected during the devastating flash flood of February 7, 2021 in the Dhauliganga valley. Keeping in these view, there is needs to promote the local inhabitants of the area to construct houses in traditional manner. This practice will reduce the losses and damages from the threat of future deluge.

6. Conclusions

On the basis of study carried out in the area, it is suggested that a massive rock fall along with glacier avalanche, multiple temporary damming of streams witnessed a flash flood situation on February 7, 2021. Due to the same phenomena, abnormal rise in water along with huge volume of debris materials and detached rocks that gushing down through the courses of the Raunthi Gadhera, Rishiganga and Dhauliganga river resulting in widespread damages, particularly in the area around Rini and Tapoban. These caused 204 persons went missing while 12 persons injured and 184 farm animals were lost in this incidence along with washed away 2 hydroelectric projects, 5 pedestrian bridges and 1 motorable RCC bridge.

Most of the habitations in the affected region has been situated on middle hill slopes and far away from the river bed. Because of the same, no damages however occurred in these during the flash flood. In view of vulnerability to flash flood, any kind of encroachment along the river bed should be prohibited in the future.

Presently, an artificial lake which formed over Rishiganga is needs detailed geomorphological evaluation as this is problematic during monsoon when it will contribute significant discharge and increasing hydrostatic pressure. Due to this, the situation of flash flood can occur again in the downstream. However, its effects can be reduced by estimating regular discharge and installing early warning system for flood forecast in the affected area.

In view of vulnerability to flash flood, flood in the region, DEM-based approaches for the delineation of flood-prone areas in an ungauged basins [1] and the recent modelling technology for determination of flood-prone and flood inundation areas [2] can be extremely useful. The same would help in taking safeguard against life and property losses in the region.

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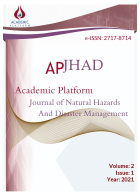

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Seismic Pounding Between Adjacent Buildings: A Review

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Abstract

The collision between adjacent buildings with an insufficient seismic separation distance has been reported after earthquakes. This collision between adjacent buildings, commonly referred to as earthquake-induced pounding, entails huge damages to the involved buildings. The main cause of damage was interpreted to the developed impact forces between colliding buildings. The intensity of the impact force relies on many factors, therefore, a significant research effort was found to address this issue from different perspectives. This paper presents a summary of the main research conducted in the context of structural pounding namely, field observations, experimental and numerical studies. The main recommendations and results of each category have been highlighted and insights for future research are provided.

Keywords: Pounding, impact force, RC buildings, separation distance

1. Introduction

Limited inhabitable land in highly populated countries is a typical problem around the globe. As such, for the optimum use of the available land, most of the existing buildings in these regions were found with no separation distance even in highly earthquake-prone regions [1]. During earthquakes, these buildings undergo lateral displacement, and, therefore, potential collisions between adjacent buildings are inevitable. The collision between adjacent structures, also known as earthquake-induced pounding, introduces waves of stress due to the impact between the adjacent buildings. These waves of stress, which are not considered during the design stage, significantly change the global response of the colliding buildings namely the loading path and, therefore, the failure mechanisms.

Based on the post-event survey after major earthquakes, adjacent buildings showed a vulnerable performance with excessive damages compared to the individual buildings [2-4]. The observed damage varies from local damages at the contact surface to more severe damages namely shear failure at beam or columns and even the global collapse. Devastating earthquake events entail huge life and economical losses particularly for those structures with inherited seismic vulnerability. Earthquakes, however, keep deepening the knowledge of the scientific community and keep raising the awareness of the scientific, technical and political community to the need of identifying assets at risk (i.e., such adjacent buildings) and developing more

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effective risk mitigation strategies. Based on the provided lessons from major earthquakes, a vast body of literature addressing the pounding effects on the structural response of adjacent structures during earthquakes have been found over the past five decades (e.g., see [5-19] among others). The research on earthquake-induced pounding was found in different scales; from studying the impact phenomena to the global performance of the adjacent structures. Also, the critical pounding configurations, these with a high probability of experiencing severe damage due to earthquakes, have closely been studied. This paper categorises the literature on earthquake-induced pounding into three main groups; studies related to the post-earthquake field observations, experimental studies, and numerical studies. An overall summary of each type of these categories has been provided with an emphasis on the points which need to be covered in future studies.

2. Problem statement and paper organization

The separation distance that mitigates the collisions between adjacent buildings is required by several design regulations [13], however, most existing buildings are found either with no separation distance or with insufficient separation [10]. As such, a collision between the adjacent buildings is expected during earthquakes. Depending on the relative dynamic characteristics of the adjacent buildings (e.g., fundamental period, mass, height, stiffness, orientation, geometry, etc.), the intensity of the collision can be classified into two scenarios as shown in Figure 1. In which for buildings with similar dynamic characteristics, the developed later displacement of the adjacent buildings will be synchronized (in-phase), therefore, no collision is expected. However, given the building-to-building variability, the adjacent buildings most likely develop different lateral responses (out-of-phase), as such, collisions between adjacent buildings with insufficient separation distance are inevitable. This collision between adjacent buildings results in different damage levels which vary from local damage at the contact locations during moderate seismic excitation or significant damage or even global collapse for more severe earthquakes as shown in Figure 2.

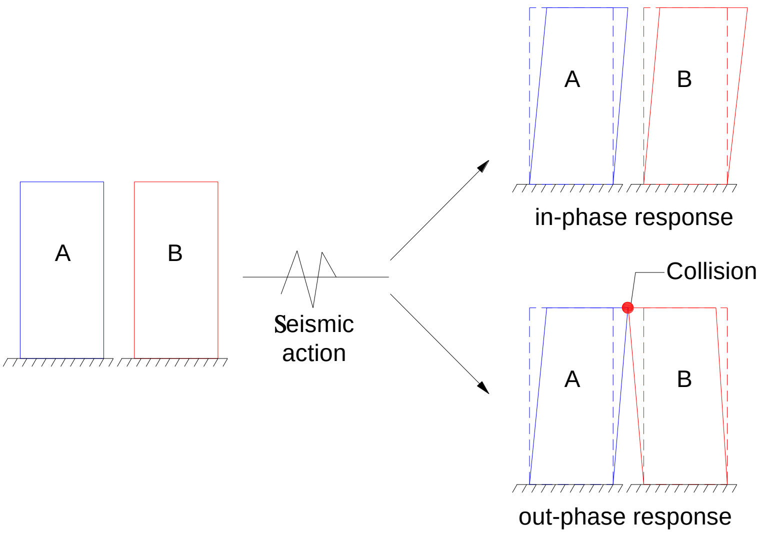

Figure 1. A Schematic sketch for the potential responses of two adjacent buildings

a) damage at contact [20] *b) damage at infill walls [20]* *c) global collapse [21]*

Figure 2. Damage pattern due to pounding effect

Field observation studies of the damage patterns of the adjacent buildings after recent major earthquakes come as the first approach for a better understanding of the seismic pounding. However, the limited available data promotes researchers to define other alternatives to closely study the earthquake-induced poundings. As typical approaches for studying similar problems, experimental and numerical studies were found in the literature to address the seismic pounding. A limited number of experimental studies were found in the literature due to the associated resources. In contrast, promoted by the limited required resources compared to experimental investigations, several numerical studies have been conducted in different scales. This paper presents first the studies related to the observed damages after recent major earthquakes. Based on these field observations, the critical configurations of pounding between adjacent buildings are presented. Thereafter, the experimental and numerical studies are presented, highlighting the main aspects of these studies and their main conclusions.

3. Field observation investigations

The great Alaskan earthquake in 1964 provided the first piece of evidence on the vulnerability of adjacent buildings with insufficient separation distance [22, 23]. Since then, structural pounding was identified as the cause of several damage patterns and mechanisms that lead to the global collapse of the inadequately separated buildings [22, 23]. Thereafter, several field observations correlated damage patterns and collapse mechanisms with structural poundings. For example, the collapse of the external stairway of Olive View hospital, after the San Fernando earthquake in 1971 showed the vulnerability of buildings at the end of a row of buildings and those with significant differences in their dynamic characteristics [24]. Also, it was observed after the Mexico City earthquake in 1985 that pounding affected over 40% of the 330 affected buildings. The pounding was the primary cause of collapse at least 15% of the pounding-affected buildings [21]. In the same context, in the survey database after the 1989 Loma Prieta earthquake over 200 out of 500 inspected buildings were found pounding-affected [20]. Whereas the pounding of adjacent unreinforced masonry (URM) buildings entailed shear failure of the brickwork leading to the partial collapse of the wall. The structural pounding was also observed in many adjacent buildings after the 1999 Chi-Chi earthquake struck centre of Taiwan. However, schools that have been expanded by new adjacent structure experienced a higher probability of damages. Whereas the old and new classrooms have a difference in height, stiffness, and mass due to the different construction times. Thus, these structures developed an out-of-response, leading to the high level of damages [25]. Similar observations were drawn after Kocaeli earthquake and North Athens for the same years [26].

The Kaliningrad earthquake in 2004 emphasised that pounding configuration plays a fundamental role in the overall behaviour of adjacent buildings. Whereas, buildings with eccentric pounding configurations exhibited local damages (plaster spalling) due to the excessive torsion strain along the contact area [27]. More recently, the observations after the Christchurch earthquake, 2011, showed that 6% of the 376 surveyed buildings in the central business district damaged by the pounding [2]. Given that unreinforced masonry (URM) buildings are the most common structures in that central district, most of the observed are located at this type of buildings. These damages are interpreted to brittle behaviour of the URM which cannot sustain the large demand of the pounding in a short period. Recently similar observations have been reported after the 2020 Sivrice-Elazığ, Turkey earthquake [28], emphasising the fragile behaviour of adjacent buildings with unaligned slabs which jeopardize the safety of the buildings due to the shear failure of the impact columns.

It can be concluded that damage observed in adjacent buildings that pounded varied from local damage in infill walls to more severe damage such as shear failure of columns and even collapse. Moreover, five pounding configurations were identified to exhibit a high probability of damage during earthquakes, which are shown in Figure 3. These configurations include adjacent buildings exhibiting floor-to-column alignments, adjacent buildings with significant mass or height differences, buildings at the end of a row of buildings, and buildings likely to experience eccentric pounding [2, 3, 16, 29].

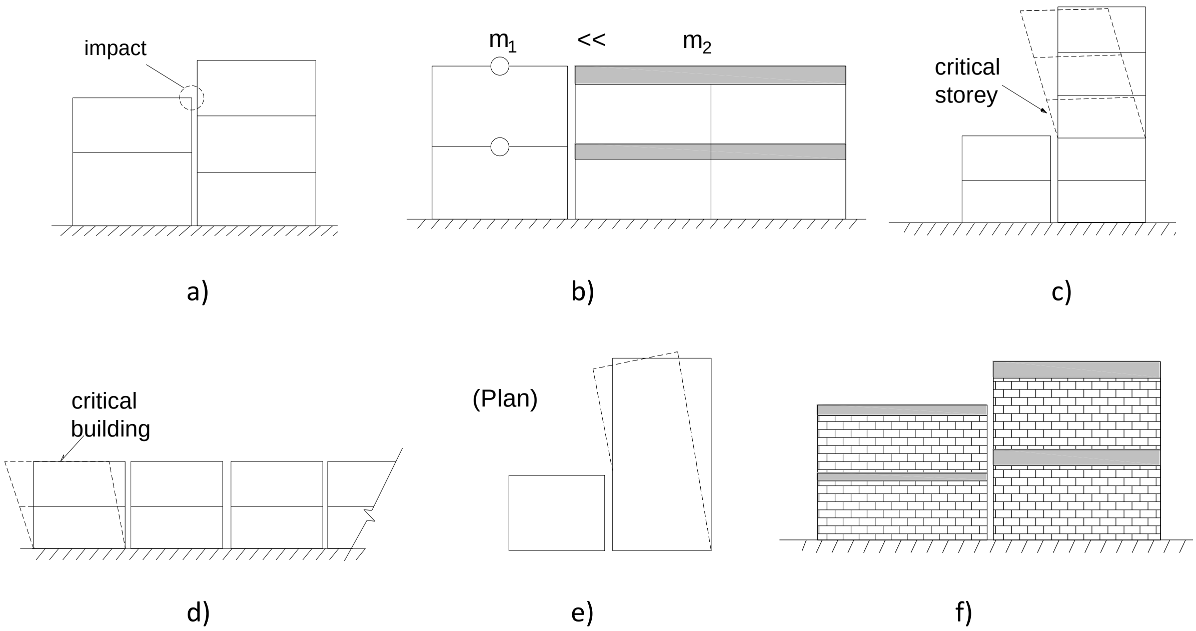

Figure 3. Critical pounding configurations after Cole, et al. [16]

4. Experimental studies

Mier, et al. [30] conducted a series of tests to investigate the impact between two concrete elements. This test has been performed in form of a pendulum experiment where strikers (concrete blocks with various front shapes) were used to impact prestressed concrete piles. Several parameters were considered in this study such as the compressive strength of the concrete element, the size of the plastically deformed zone in a static test, etc. Based on this test, a proposal for the definition of the contact parameters based on a static test has been introduced. Papadrakakis and Mouzakis [31] tested one-bay-building adjacent frames with two storeys using a shaking table simulator. The structures were designed to maintain their elasticity under the imposed excitation with a design spectrum of 1.0 g. Furthermore, the dynamic characteristics of the tested frames were adjusted to simulate the scenario of a stiff building adjacent to a flexible building with no gap distance. The structures were subjected to a ramped sinusoidal displacement signal having a peak displacement of 0.13 cm and at resonance with the fundamental frequency of the flexible structure (f = 4.1 Hz). Based on the experimental measurements, they concluded that acceleration responses for the tested frames were dramatically increased (six-fold increase) due to the pounding effect. Due to the tested frames were well-designed and the low level of excitation, this test did not provide further information regarding the damage pattern. Chau, et al. [32] carried out a series of shaking table tests to estimate the pounding responses between two steel towers with different natural frequencies, damp ratios, and separations. The structures were subjected to sinusoidal waves of various magnitudes and frequencies, as well as the ground acceleration of the 1940 El Centro earthquake. It was found that pounding generates a significant amplification in the response of the stiffer structures and reduces the flexible structure's response. It was found that the maximum relative impact velocity occurred at an excitation frequency between the natural frequencies of the two structures. Rezavandi and Moghadam [17] conducted shaking table experiments on reduced-scale moment-resisting one-bay steel frames subjected to harmonic excitation and real seismic ground motion. Series of tests were performed to investigate the effect of the distance between the buildings, impact-absorbing material, and the case when adjacent frames are connected. Experiments and numerical analyses have revealed both the effectiveness and drawbacks of each method for reducing pounding effects. However, impact-absorbing materials were found to be more effective in reducing the pounding effect. Furthermore, they concluded that frame responses were highly sensitive to the gap between them. More recently, Jankowski, et al. [14] performed a shaking table test on pounding using three reduced-scale steel frames with various configurations and different gap separation distances between them. In addition to the obvious conclusions drawn by previous researchers, this test referred to that the increase or decrease of the gap distance may lead to the increase or decrease in the response under different earthquakes with no specific trend.

In a general sense, these studies emphasised that structural pounding has a great contribution to the dynamic response of adjacent buildings and this contribution should not be discarded. However, as can be seen, a limited number of experimental tests were found. In addition, most of the experimental tests were performed using a single degree of freedom or reduced scale steel frames. Furthermore, most studies emphasised the difficulty of obtaining precise measurements; some studies suggest that accelerometers be supplemented with acoustic signal sensors and video recorders. Given the scarcity of experimental results in full-scale buildings, numerical modelling, in particular detail micro-model, can be used as a proxy for the experimental tests.

5. Numerical studies

Modelling earthquake-induced pounding between buildings requires using an accurate numerical model, particularly that simulates the impact between the colliding bodies. In this context, existing numerical studies can be divided into two types: element-level studies that focused on modelling and developing the collision model between adjacent buildings, and the structure-level studies which focused on structures' response considering the collisions by using predefined impact element. The main objective of the former-mentioned studies is to define a reliable numerical model to simulate impact phenomena. On the other hand, using the recommendations of element-level studies, the structure-level studies aim to define the effect of the pounding on the overall behaviour of adjacent buildings in a more comprehensive way. The next sections will briefly address these numerical studies, highlighting their main objectives and findings.

5.1 Numerical studies in element-level (impact modelling)

As referred before, the vast majority of the research that tackled pounding relied on numerical simulation due to its feasibility compared to the experimental tests. Whereas the reliability of the model that simulates the impact phenomena is the key element for realistic numerical simulations, several numerical studies have been developed to address this issue (e.g., see [33-36] among others). These studies highlighted that adequate modelling of the impact between adjacent buildings is fundamental. The general idea of modelling the impact between two adjacent buildings is to define the interaction between the two bodies during and after the impact using predefined mathematical rules. Two approaches with different theoretical-based were found in the literature to model the impact between colliding bodies: *stereo mechanics approach and force-based approach*. Depending on the impact stag, these approaches provided different mathematical formulations for the impact. To recognize these stages, Figure 4 shows two spherical bodies at different stages of impact. As can be seen, the two bodies with mass m_1 and m_2 are approaching each other with velocity v_1 *and* v_2 (at left) and getting closer until the penetration displacement δ equals zero, in which the impact is imminent. Thenceforth, the two bodies are called in the *approach phase*. At that stage, the penetration distance δ and relative velocity dv are larger than zero. This phase ends when penetration distance δ reaches to δ_{max} value and dv equals zero. From that point, the two bodies start to separate which is called the *restitution phase*. The restitution phase lasts until δ reaches zero again with final velocities v'_1 *and* v'_2 for m_1 and m_2, respectively. The main idea behind the impact numerical model is to modify the dynamic response of the colliding bodies according to their impact stage. The next sections present the referred approaches (i.e., stereo mechanics approach and force-based approach), highlighting their privileges and drawbacks.

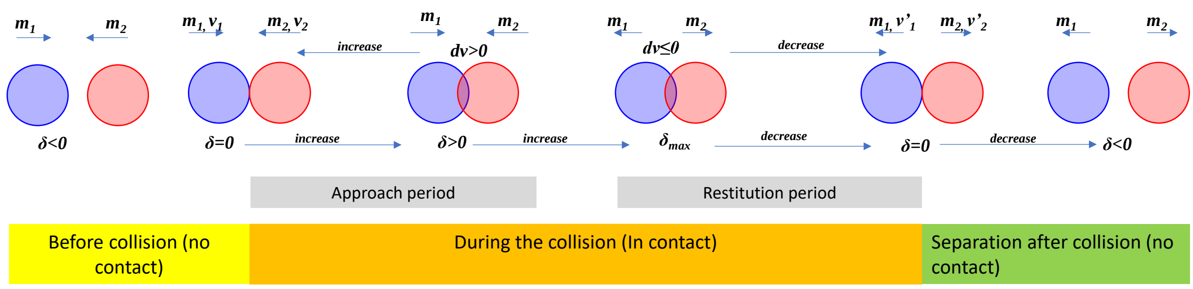

Figure 4. Schematic diagram of the impact between two spherical bodies at different impact stages

5.1.1 Stereo mechanics-based model

Despite being less common in use nowadays, the classical theory of impact (stereo mechanics) method still represents an important concept. In a general sense, stereo mechanics theory determines the post-collision velocity of colliding elements without tracing structural response by considering the conservation of momentum over the duration of impact [37]. Based on this theory, the final velocities of two bodies with m_1 and m_2 masses that impacted at initial velocities of v_1, v_2, respectively, can be determined as follows:

$$v'_1 = v_1 - (1+e)\,\frac{m_2}{m_2+m_1}\,(v_1 - v_2) \tag{1a}$$

$$v'_2 = v_2 + (1 + e)\ \frac{m_1}{m_1 + m_2}\ (v_2 - v_1) \tag{1b}$$

Where v'_1, v'_2 are the final velocities (i.e., after impact, see Figure 4) for the two bodies, respectively, and e is a coefficient of restitution. The coefficient of restitution (e) is defined as the ratio of the separation velocities of the bodies after impact to their approaching velocities before impact, which can be obtained from the equation:

$$e = \frac{v'_2 - v'_1}{v_1 - v_2} \tag{2}$$

The coefficient of restitution is a measure of plasticity in the collision. It depends on the relative shapes of the colliding structures, their material properties, and masses. The value of $e = 1$ corresponds to the case of a fully elastic collision, while the value of $e = 0$ deals with a fully plastic impact. Even though this approach has a rigorous theoretical base, its use is limited in the literature of the pounding between adjacent buildings due to the involved limitations regarding the tracing stresses transformation between the colliding bodies [37, 38]. These limitations due to the fact that the *Stereo mechanics*-based model focuses only on the determination of the velocity of colliding elements after the collision assuming that impact lasts for a negligibly short time therefore, this approach does not consider the transformation of stresses and deformations between the element of colliding bodies during impact. Furthermore, for multiple degrees of freedom system when several colliding expected at various time, the application of the Stereo-mechanics based model is seen as infeasible [34].

5.1.2 Force-based models

The ability of the force-based approach to simulate the interaction between the colliding bodies in terms of stresses and deformation enables to overcome the limitations of the *Stereo mechanics*-based model. Moreover, their inherited simplicity and ability to be incorporated into time history analysis programs facilitated the widespread use of this approach [10, 36, 38]. The base of this approach is to impose a force during the impact between the colliding bodies which is known as impact force F. The impact force represents the measure to consider the interaction between the two bodies considering the relative dynamic characteristics of the colliding bodies. For clarity, the two structures 1 and 2 that are shown in Figure 5, are considered. The equation of motion of the two systems 1, 2 oscillating under an earthquake excitation $\ddot{u}_g$ can be expressed as:

$$\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} \begin{Bmatrix} \ddot{u}_1 \\ \ddot{u}_2 \end{Bmatrix} + \begin{bmatrix} c_1 & 0 \\ 0 & c_2 \end{bmatrix} \begin{Bmatrix} \dot{u}_1 \\ \dot{u}_2 \end{Bmatrix} + \begin{bmatrix} k_1 & 0 \\ 0 & k_2 \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} + \begin{Bmatrix} F \\ -F \end{Bmatrix} = -\begin{bmatrix} m_1 & 0 \\ 0 & m_1 \end{bmatrix} \begin{Bmatrix} \ddot{u}_g \\ \ddot{u}_g \end{Bmatrix} \tag{3}$$

in which $u_i, \dot{u}_i$ and $\ddot{u}_i$ are the response in terms of displacement, velocity, and acceleration, respectively, of the ith system (1 or 2, according to the suffix) along the excitation direction, while m_i, c_i and k_i are the mass, damping and stiffness matrices, respectively, of the ith system (1 or 2, according to the suffix). The vector $\{\mathrm{F}, -\mathrm{F}\}$ contains the impact forces representing the interaction between the two systems during the collision otherwise, this vector will be null. Several proposals were found to express F as a function of the relative displacement between the colliding bodies, with linear or a nonlinear force relation and with/without viscous damper, [10, 34, 38]. Table 1 provides a brief description of these types along with their main modelling features. As can be noticed that the modelling of impact forces evolved from linear spring with no energy dissipation capabilities to these with full energy dissipation capabilities through nonlinear relation between the impact force and the penetration along with that dissipated in damping. Even though the latter is more accurate in terms of simulating the real behaviour, the former model (i.e., linear viscous model) was found to be more efficient for computationally-intense applications such as performance-based studies due to its balance between simplicity and accuracy [10, 36, 38].

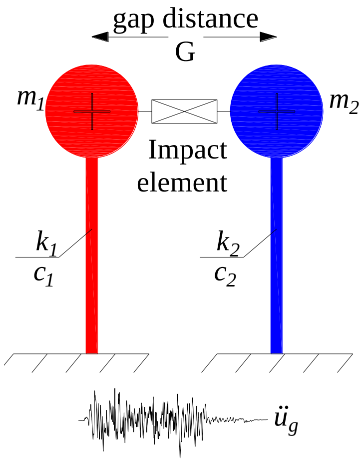

Figure 5. Representation of the force-based approach for two structural systems oscillating due to earthquake excitation

5.2 Numerical studies in structure-level

Based on the developed models in the previous section, several studies involved realistic building configurations were conducted to address the significance of the pounding effect on the global structural response during seismic actions (e.g., see [6, 8] among others). The manifold parameters involved result in multidirectional studies. Some of these studies were detected to quantify the safe separation distance between adjacent buildings, (e.g., see [44-48] among others). Other studies were conducted to investigate the effect of the dynamic characteristics of the involved structures either using a deterministic approach (e.g., [8, 49] among many others) or using a probabilistic approach [6, 50]. However, due to the high computational costs for the probabilistic approach particularly when the impact element is involved, the latter approach was found in a limited number of studies compared to the former approach. Moreover, others tackled the site and soil condition of the adjacent building [13, 51]. Eventually, the mitigation measures were presented in many studies as in [6, 52, 53].

As a general conclusion of all presented studies, the pounding effect reduces the displacement response of adjacent buildings on their impacted side and amplifies the displacement response on their unimpacted side [8, 13]. Additionally, pounding was also found to increase the acceleration response of the adjacent buildings during the impacts. However, the majority of these studies addressing the pounding phenomenon have limitations, i.e., none of them addressed the situation of the buildings at the end of a row of buildings also or these studies analysed the effect of pounding using a limited number of ground motion records. As such, results from previous research are not seen to be fully generalized [3, 6, 13, 16, 54]. Therefore, probabilistic studies should be carried out to analyse the significance of the pounding phenomena on the global response of structures.

Table 1. Impact force F based on various force-based model

model [reference]	Theoretical expression			Main feature	Damping ration expression	Notations
	Approach phase $u_1 - u_2 > G$ & $\dot{u}_1 - \dot{u}_2 > 0$	Restitution phase $u_1 - u_2 > G$ & $\dot{u}_1 - \dot{u}_2 \leq 0$	#After /before impact			
Linear impact model (*Kelvin-Voigt model*) [33, 39, 40]	$F = K(u_1 - u_2 - G)$		0	Linear model Kelvin-Voigt model	None	K is the spring stiffness in form of *f/d* where *f* is in the force unit and *d* is in the displacement unit
Linear viscoelastic *Modified Kelvin-Voigt model*	$F = K(u_1 - u_2 - G) + C(\dot{u}_1 - \dot{u}_2)$		0	Count for the energy dissipation by considering the damping term	+$C=2\zeta\sqrt{K\left(\frac{m_1 m_2}{m_1+m_1}\right)}$ where $\zeta = -\frac{\ln e}{\sqrt{\pi^2+(\ln e)^2}}$	
Modified Linear viscoelastic model [35]	$F = K(u_1 - u_2 - G) + C(\dot{u}_1 - \dot{u}_2)$	$F = K(u_1 - u_2 - G)$	0	Eliminates the tensile force at the restitution phase	$\zeta = \frac{1-e^2}{e(e(\pi-2)+2)}$	
Hertz model [37, 41]	$F = K_h(u_1 - u_2 - G)^{3/2}$		0	Introduce nonlinear form for the impact force which is a more effective way	None	
Hertzdamp model [36]	$F = (u_1 - u_2 - G)^{3/2}[K_h + \bar{\zeta}(\dot{u}_1 - \dot{u}_2)]$		0	Count for the energy dissipation by considering the damping term	$\bar{\zeta} = \frac{3K_h(1-e^2)}{4(\dot{u}_1 - \dot{u}_2)}$	K_h is the impact stiffness in form of $f/m^{3/2}$
Modified nonlinear viscous model [34]	$F = K_h(u_1 - u_2 - G)^{3/2} + C_h(\dot{u}_1 - \dot{u}_2)$	$F = K_h(u_1 - u_2 - G)^{3/2}$	0	Eliminates the tensile force at the restitution phase	$* C_h = 2\check{\zeta}\sqrt{K_h\sqrt{(u_1 - u_1 - G)}\frac{m_1 m_2}{m_1+m_2}}$ $\check{\zeta} = \frac{9\sqrt{5}}{2}\frac{1-e^2}{e(e(9\pi-16)+16)}$ [42]	

⁎ modified versions of ζ have been proposed in
+Based on [43]
#$u_1 - u_2 \leq G$

Conclusions

This paper presents a review of the research that tackled the seismic pounding between buildings. These studies were categorized into three main groups: field observation studies, experimental studies, and numerical studies. As a general conclusion for all these studies, structural pounding changes the dynamic response of the adjacent structures and using mitigation measure are highly recommended. Also, for the numerical modelling of impact element, it can be concluded that, even though the nonlinear model is more accurate in terms of simulating the real behaviour, the linear model (i.e., linear viscous model) was found to be more efficient for computationally-intense applications such as performance-based studies due to its balance between simplicity and accuracy. Moreover, given the scarcity of fully reported experimental results, additional testing should be conducted. These tests should provide comprehensive information on the response of the building during impact, the damage pattern, and the mechanism that leads to the collapse. Eventually, this paper found that the majority of the presented studies were conducted for buildings with aligned slabs, therefore, more investigation should be carried to consider other configurations such as floor-to-column alignments, adjacent buildings with significant mass or height differences, buildings at the end of a row of buildings, and buildings likely to experience eccentric pounding.

Author Contribution

Mohamed, H., and Elyamany, G., collected, analysed the literature review and wrote the manuscript with input from all authors. Mohamed, H., and Khalil, E., contributed to the revision of the manuscript and supervising the research.

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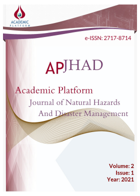

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Determination of Shear Strength Parameters by Multistage Triaxial Tests in the Long-Term Analysis of Slopes

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Abstract

Accurate determination of soil parameters is of great importance in the analysis of landslides, which is a common type of natural disaster. In the solution of landslide problems, the direct shear box test is generally preferred as a laboratory test type for the determination of the shear strength parameters of soils. However, the need for drained parameters in long-term problems reveals a disadvantageous aspect of this experiment, especially in clayey soils, because pore water pressures cannot be measured in the direct shear box test, which is widely used in the laboratory to determine the shear strength of the soils.

Multistage triaxial compression tests used to obtain shear strength parameters in the laboratory are advantageous compared to conventional triaxial compression tests because of the time and financial concerns, as well as the avoidance of differences between the samples to be tested. In this study, a new method was tried in addition to the methods used to obtain shear strength parameters with consolidated-drained multistage tests in normally consolidated clayey soils and the results were promising. Thus, since it increases the usability of multistage tests, it will be helpful in terms of preventing possible disasters by enabling analysis in many more sites.

Key words: Landslides, multistage triaxial test, long-term analysis

1. Introduction

In the analysis of landslides, it is crucial to correctly determine the soil's cohesion and internal friction angle. Stability problems of natural slopes are determined by effective parameters in the long-term analysis. To assess these effective parameters in the laboratory, it is necessary to measure the pore water pressures, which change with increasing axial stresses. Direct shearing tests and triaxial tests are widely used in the laboratory to measure effective shear strength parameters. Since pore water pressure measurements cannot be made during conventional direct shear box tests, it is impossible to control whether the test is drained or not, especially on clayey soils. Although there are methods to determine the shearing rate for drained shearing in the literature, the fact that there is no direct observation of a change in pore water pressure makes the test questionable. Therefore, it is preferable to perform the drained tests on clayey soils with a triaxial test.

Consolidated-undrained (CU) or consolidated-drained (CD) test type is preferred to find the effective shear strength parameters in the triaxial test. CD tests, which are also used in the analysis of slope stability, are the tests in which the effective shear strength parameters are

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obtained and must be conducted very slowly to prevent excess pore water pressures in the sample in low permeability soils. The effective shear strength is determined by the tests performed on the core samples taken from the field to define the soil properties where the stability analysis will be performed. Sometimes, it is necessary to work with several samples in the same layer at the same depth, and at least three tests should be carried out on the specific soil to determine the shear strength. There will likely be differences between core samples taken from the field in this standard practice, and standard CD tests take a lot of time to run. Besides, economic concerns cannot be ignored.

The multistage CD tests on a sample representative of the soil property can be used to save time and reduce costs in applications where embankment dams, excavations in soft and solid clays or the stability of slopes are the most critical conditions. Within the scope of this study, multistage CD tests, which are considered practical compared to conventional methods, were used in the rapid and economic analysis of natural disasters, such as landslides, where slope stability should be examined. Conventional triaxial tests and multistage testing were performed on normal consolidated clayey silt samples. In order to obtain the effective shear strength parameters of the samples, a new method has been proposed and evaluated besides the method used in the literature. Kondner's [1] hyperbolic relationships were used to estimate the deviator stress at failure from stress-strain data obtained from multistage tests [2]. Nambiar [3] mentioned that an additional conventional test should be performed in order to obtain shear strength parameters from multistage tests. Within the scope of this study, obtaining shear strength parameters from multistage tests with a new method without the need for an additional conventional test was investigated.

2. Testing Program and Results

The soil used in this study was classified as a clayey soil (CL) according to the TS-1500 [4]. The soil is consists of 27% clay, %73 silt. It has specific gravity of 2.66, liquid limit of 30.3%, plastic limit of 22.85%, maximum dry unit weight of 15.18 kN/m^3 and optimum moisture content of 25.63%. Prior to the multistage test, conventional consolidated drained (CD) tests were performed on the samples to determine the cohesion and angle of internal friction. In this way, it was aimed to compare the shear strength parameters obtained from conventional tests with those obtained from the multistage test.

The consolidated drained (CD) tests were performed on reconstituted cylindrical samples. Reconstituted cylindrical samples were prepared with the uniaxial consolidation of soil slurries method. Samples were reconstituted at 100 kPa consolidation pressure. According to ASTM D7181 [5], a sample dimensions ratio (height to diameter) between 2 and 2.5 is recommended. Therefore, reconstituted samples had dimensions of diameter 50 mm and height of 100 mm. In both conventional and multistage tests, the preparation of the sample and its placement in the triaxial test apparatus was performed identically.

The lines were saturated by flushing water through de-airing and checking of the connecting lines and the drainage system. The reconstituted sample with top, bottom, and side filters was placed on a base pedestal with top and bottom saturated porous disks. Afterward, placing the specimen in position, a standard rubber membrane was used to contain the samples laterally, and two pairs of O-rings were used to fit the rubber membrane with each of the base pedestal and the top cap to ensure the separation of the cell and back pressures applied to the samples. By assembling the test equipment and filling the test cell with water, the sample was ready for the triaxial test.

Each conventional triaxial test consisted of three phases: saturation, consolidation, and shearing. During the saturation phase of the test, the sample was subjected to incremental confining or cell pressure steps $\sigma_c = \sigma_3$ between 50 and 500 kPa, along with back pressure differential was 10 kPa, that is, incremental back pressure steps 40 and 490 kPa. With the B value calculated in each step of the saturation phase, it was followed whether the sample was at 95% saturation. The objective of the saturation phase of the test is to replace the voids in the sample with water and prevent the formation of different undesirable stresses in the sample, and this process can take days from time to time in unsaturated samples. In this study, the saturation phase lasted between 2 and 3 hours because the reconstituted samples were saturated. The saturation phase was applied the same in both conventional and multistage test.

In the consolidation phase, the sample was consolidated by creating the same stresses in whatever effective stress the specimen will be shear in the shearing phase. During consolidation, the sample reached equilibrium in a drained state, and the strain rate to be used in the shearing stage was determined with the data obtained at the consolidation stage. During the consolidation phase of conventional triaxial tests, data is obtained for use in determining when consolidation is complete and computing a strain rate to be used for the shear portion of the test. The strain rate was determined by following the ASTM D7181 [5] standard with the t_{90} parameters obtained from the square root time and deformation graphs. When the strain rates used in the literature are examined, Ho and Fredlund [6] used the consolidation coefficient for the selection of the strain rate in their multistage tests on unsaturated soils and the strain rate was 0.001 mm/min; Banerjee et al. [7] conducted multistage consolidated-drained tests on unsaturated clayey soil and the strain rate was 0.003%/min; Hormdee et al. [8] used 0.002%/min as the strain rate in their multistage tests on silty clayey soils. Sharma et al. [9] determined the strain rate as 0.005%/min in order to have enough time to end each loading stage and then move on to the next stage in multistage consolidated-drained tests conducted on silty sands. Also, in general laboratory tests, Skempton [10] suggested a shearing rate of 0.005 mm/min. Considering the data obtained from the consolidation phase and literature studies, the strain rate was determined as 0.005 mm/min.

In the shearing phase that started after the consolidation phase, the samples were subjected to confining pressures of 100, 200, 300 kPa to determine the Mohr strength envelopes. The samples were sheared until 20% deformation occurred in the samples.

The stress-strain curves of conventional triaxial tests (CTTs) to check the accuracy of the data in multistage test are shown in Figure 1. The effective shear strength parameters according to the failure envelope created by using peak deviator stresses in stress-strain curves obtained from conventional tests are as follows: c'=20.98, ϕ'=33.17.

Ho and Fredlund [6] mentioned two methods in multistage shear tests. One is the cyclic loading method, in which the load on the sample is removed after the shearing is terminated and the next consolidation stage is passed, and the other is the sustained loading method, in which the load is maintained in the consolidation phase after the shearing is terminated. In the sustained loading method, keeping the load on the sample between stages might continue to deform the sample. For this reason, cyclic loading method was preferred in this study for multistage triaxial test. Figure 2 shows the stress-strain curve obtained from cyclic multistage test (MST).

In multistage test, the sample was subjected to all of the effective stresses applied in conventional tests to determine the Mohr strength envelope in increasing order. After the multistage test specimen was saturated as in the conventional test, it was consolidated at effective stress of 100 kPa and then sheared at the same effective stress. The sample was sheared to a certain deformation was consolidated by subjecting it to effective stress of 200 kPa for the second consolidation. After the second consolidation, the sample was sheared to a certain deformation with effective stress of 200 kPa and subjected to effective stress of 300 kPa for the third consolidation. The effective stresses at each consolidation stage were the same as the effective stress value in the shearing stage following the consolidation stage. In each shearing stage of the multistage test, a shearing rate of 0.005mm/min was used as in the conventional tests. In this study, the multistage test was carried out by shear the sample until it reached a deformation of 4.5% in the first two stages and in the third stage, which was the last stage, until the sample reached 20% deformation. The stress-strain curves of the multistage test (MST) are shown in Figure 3.

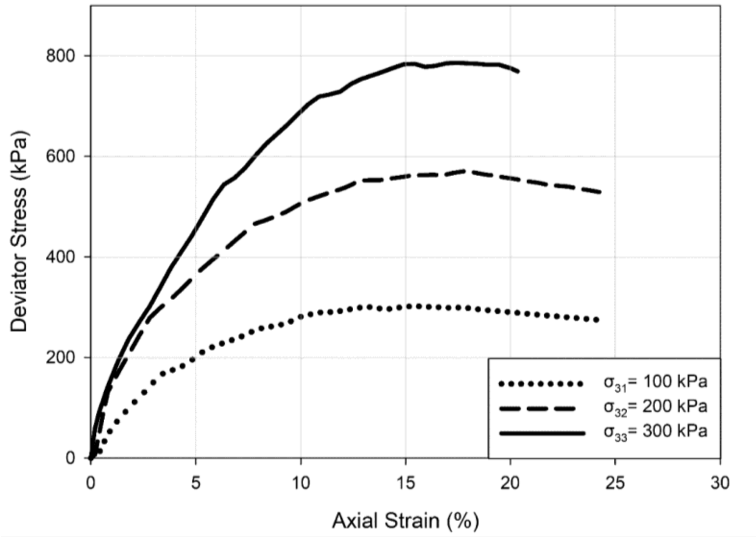

Figure 1. Stress-strain curves of the CTTs

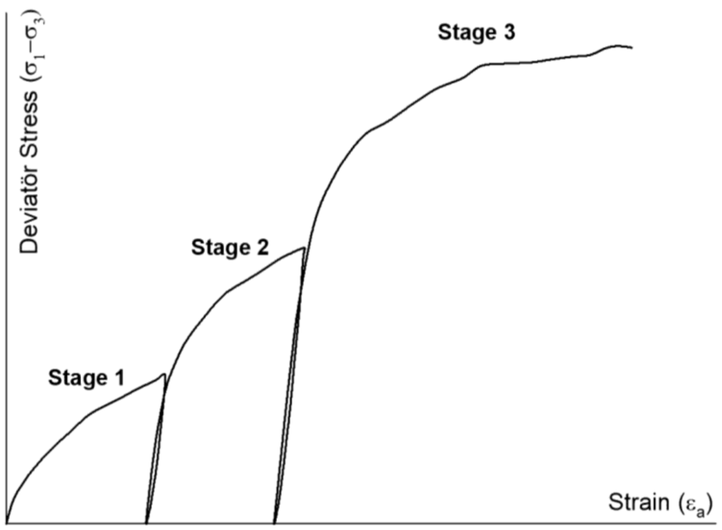

Figure 2. Stress-strain curve of the cyclic MST

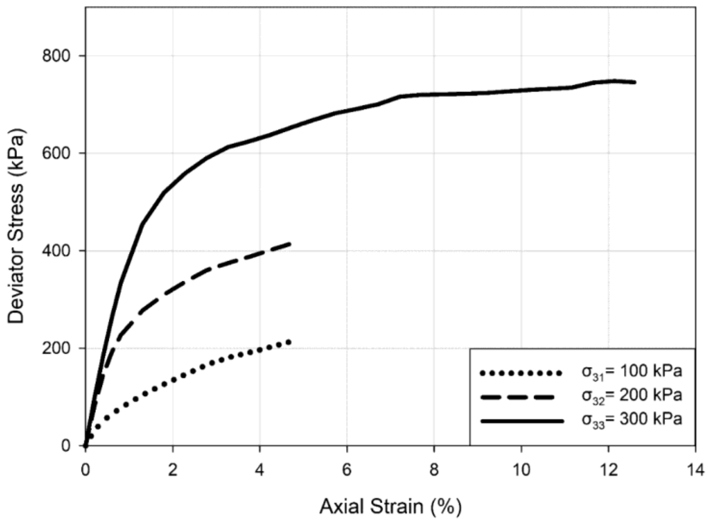

Figure 3. Stress-strain curves of the MST

Kondner's [1] hyperbolic relationships were used to estimate the deviator stress at failure from stress-strain data obtained from multistage tests [2]. Kondner's method mathematically expressed as:

$$\frac{\varepsilon_a}{\sigma_1 - \sigma_3} = a + b\varepsilon_a \quad (1)$$

where; ε_a is the axial strain, $\sigma_1 - \sigma_3$ is the deviator stress, a and b are empirical constants that can be obtained experimentally from Kondner's linearization. A plot of $\varepsilon_a/(\sigma_1 - \sigma_3)$ vs. ε_a is a straight line in which its slope gives the value of b, and its intercept with the axis of $\varepsilon_a/(\sigma_1 - \sigma_3)$ gives the value of a [11].

The hyperbolic linearization of the data obtained from the multistage test using Eq.1 is depicted in Figure 4. The stresses at 20% deformation of the lines formed using this linearization were accepted as the deviator stress. The effective shear strength parameters obtained by forming the failure envelope with these deviator stresses are as follows: c′=12.39, ϕ′=32.59.

In this study, estimated stress-strain curves were created with the data obtained from the multistage test using Eq.2 the 2-parameter logarithmic equation with the curve fitting method in statistical software.

$$y = y_0 + alnx \quad (2)$$

where; x is the axial strain; y: is the deviator stress, y_0 and a are constants obtained for Eq.1 by introducing the multistage test data into the statistical software.

The estimated stress-strain curves with the curve fitting method are shown in Figure 5. Accordingly, the estimated deformation curves obtained from the first and second stages seem to be quite compatible with the curves obtained from conventional tests, but the same compatible is not available for the final stage. The axial deformations in the first and second stages were kept within the range of 2-4% in order to prevent plastic deformations from occurring in the sample during multistage tests, and the estimated deviator stresses to be obtained from Kondner and curve fitting methods were insufficient due to the low stress-strain data obtained [12].

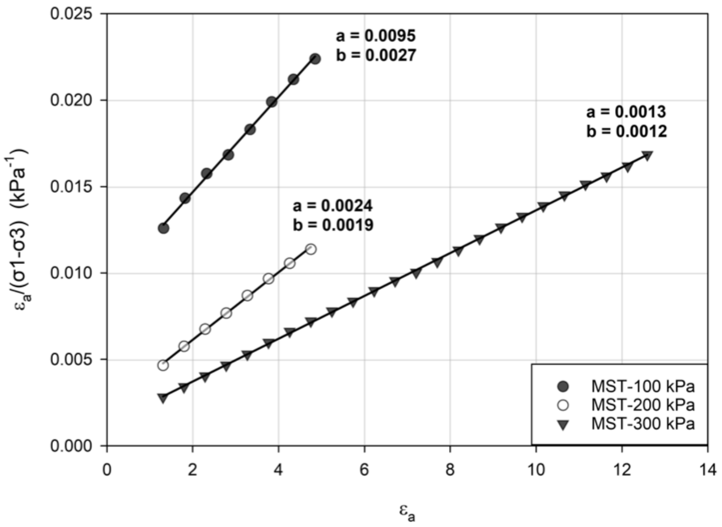

Figure 4. Hyperbolic linearization of the MST

It is thought that the estimated stress for 20% deformation with the curve fitting method at the final stage is greater than the stress obtained from conventional tests using 300 kPa confining pressure, which would be misleading for the estimation of shear strength parameters. The results obtained with the curve fitting method for all three stages are as follows: c′=2.16, ϕ′=35.81. In the Pagoulatos study [13], it was mentioned that the peak deviator stress could be taken from the last stage, since failure occurs in the last stage of the multistage test. The effective shear strength parameters obtained by using the peak deviator stress obtained from the last stage of the multistage test and the 20% deformation stresses of the curves formed by the curve fitting method to create the failure envelope are as follows: c′=29.5, ϕ′=31.84. The closeness of the shear strength parameters obtained by the curve fitting & MST peak deviator method with those obtained from conventional tests indicates that this method can be used.

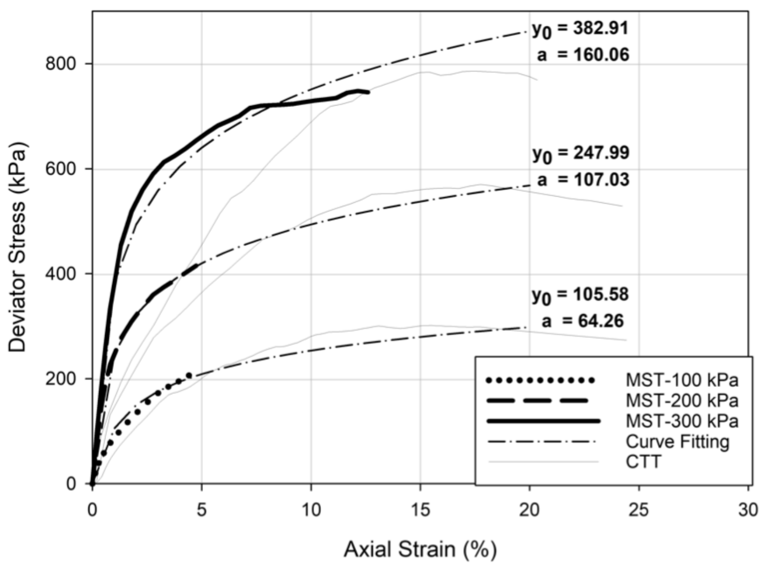

Figure 5. Stress-strain curves of the MST test with curve fitting method

When the shear strength parameters obtained by both the Kondner method and the curve fitting & MST peak deviator methods are examined, it is seen that the angle of failure values are very close to each other. However, it is difficult to mention the same agreement for cohesion strength. The cohesive strength obtained from the first method was lower than that obtained from the conventional tests, and the cohesive strength obtained from the second method was higher than that obtained from the conventional tests. The averages of the cohesion values obtained from the two different methods used in this study were found to be close to the results obtained from the conventional tests. The shear strength parameters obtained by using different methods within the scope of this study are summarized in Table 1.

Table 1. Shear strength parameters obtained from the methods

	(1) CTT	**(2) MST** Kondner	**(3) MST** Curve Fitting	**(4) MST** Curve Fitting & MST Peak Deviator St.	**(5) Average Values** *(2:4)*
c′	20.98	12.39	2.16	29.5	20.95
ϕ′	33.17	32.59	35.81	31.84	32.22

3. Conclusions

It is essential to determine soil parameters in the analysis of landslides, which is one of the frequently encountered natural disaster types. The last a long time of the experimental processes and the need for multiple samples have strengthened the concept of multistage in obtaining the drained shear strength parameters needed for long-term analyses. Preventing variations in samples and minimizing financial and temporal concerns make multistage tests advantageous compared to conventional tests. This can make the analyzes of landslides more practical and make much more analysis, thus minimizing loss of life and property. Of course, at this point, the accuracy of the results obtained from multistage tests is crucial.

In this study, consolidated drained multistage test and conventional triaxial tests were carried out on normally consolidated clayey soils. A new method has been proposed by using the method applied in the literature to obtain shear strength parameters from the multistage test without the need for another conventional test. The new method resulted in 0% and 3% difference for the estimated shear strength parameters c′ and ϕ′ obtained from the multistage test, respectively, when compared with parameters obtained from conventional tests. Although this new method was tested for a single soil type, the results were promising. This developed method can be tested on different soils and the study can be improved.

Author Contribution

Kayaturk and Bol designed the model and the experimental framework. Kayaturk conducted the experimental process and performed the calculations. Kayaturk, Bol and Sert wrote the manuscript with input from all authors. Kayaturk, Bol and Sert and Ozocak contributed to the analysis of the results.

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Evaluation Of Community Preparedness On Flood Management; A Public Survey In Kano Metropolitan

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Abstract

Flooding is one of the frequent natural/human-induced phenomena, which occurred annually for decades in Nigeria. This disaster claimed several lives and properties worth more than N6,120 Bn (which is close to the 2016 budget of the country, Nigeria). Flooding usually occurs in Kano because of lack of community participation, blockage of water drainage as well as lack of law enforcement to force people living in prone areas to vacate. The focus group discussion (FGD) was employed as a tool for data collection. The sampling frame is all district-heads, (Local Government Emergency Management agency) LEMA representatives, and other stakeholders in each local government area. The purposive-sampling technique was adopted in selecting the respondents. It is found that the majority of the respondents believed that climate change is one of the causes of flooding. Others include lack of urban planning, indiscriminate dumping of refuse in the drainage, lack of community participation, etc. Some of the responses made by the respondents about their preparedness are after flooding took place. Some of the recommendations made by this paper include non-structural responses, which include more accurate flood forecasting through the use of satellites, high-tech equipment, zoning and land-use policies, insurance programs, evacuation planning, and public enlightenment programs to sensitize people on the consequences of flooding.

Key words: Kano Metropolitan, flooding response, mitigation, recovery

1. Introduction

Disaster is the effect of a hazard on society, usually as an event that occurs over a limited time span in a particular geographic area. The term disaster is used when the interaction between humans and a natural process results in significant damage of properties, injuries, or loss of life. A catastrophe, simply put, is a massive disaster, requiring the significant expenditure of time and money for recovery [1].

Flood disaster is the commonest and frequent environmental problem in the world today [2]. It is recorded that in 2012 alone flooding caused a loss of a significant amount of money which exceeded $19.6 billion, destroyed more than 590,000 houses, and claimed the lives of more than 360 people Nigeria emergency management agency [3]. This common environmental problem, but hazardous causes psycho-environmental as well as socio-economic effects to the people been affected by it. Mammoth of billion US dollars were lost via aftermaths of flooding through washed off farmland, devastating homes, and so on. It also spread waterborne and

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vector diseases, physical injuries and death. Loss of relationship or neighborhood and many people lost their homes [4], [5].

For the African continent, flooding caused a loss of property worth about US$832 million in 2012 alone. Nigeria experiences different types of flooding; fluvial and coastal due to the nature of its location [6]. A devastating flood was recorded in Ibadan city when Nigeria became Republic in 1963, where the River Ogunpa flood claimed many lives and properties [7]. As the most populous country in Africa, in 2012, Nigeria recorded the worst flooding, which never experienced in the last four decades affected almost all the states particularly the northern part of the country because heavy rainfall lasted for many days. This affected more than 7 million people [3]. Kano is one of the states that have been affected by floods badly often [8]. According to the Kano State Relief and Emergency Agency (SREA), at least 5,300 houses were destroys by flood in six Local Government Areas of Kano State in 2016 [9].

It attracts the attention and interest of professionals from different fields of study. Researchers and practitioners look at flooding from a different perspective and take some portion of it to study such as causes, frequencies of occurrence, effects, impacts, and remedies of it. For example in the field of geography they looked at the analysis of vulnerability to flood disaster [10], [11]; research from the field of health, studied the effects of flooding on the heath [12], [13]; Microbiology studies flooding and waterborne and vector disease [4]. Engineers study mostly related technologies intending to create a model or to curb the menace of flooding [7], [14] while researchers from the field of geo-informatics focus more on mapping and modeling flood risk areas [15], [16]. Economists heed their attention on monetary effects of flooding [8], [17].

In the Nigerian context, flooding is categorized based on the location of its occurrence and the effects put on the nearby people. The urban and rural areas experience flooding mostly occur due to heavy downpour, coastal flooding (which occurs in a coastal area and affects most coastal areas) and the last is fluvial flooding (which occurs as a result of an overflow of a river due to breaking or overtopping natural or manmade barriers) [9].

It is a tradition of people to wait for government in some aspects that can easily manage and control by the community. The same people will bear the consequences first and victimizing their lives. People do not want to spend their money, time or energy on issues that matter to them. This is what makes people have an ‘I don’t care attitude’ or concrete plan and get ready against conditions or situations that have a potential impact on causing harm, injury, diseases, or loss of life during a disaster.

Urbanization is also a factor that might lead to flooding in some areas of the municipality. As soon as the human being starts to congregate even in small villages, certain practices are set in motion that enlarges the settlement into towns, cities, metropolises, conurbations, etc. Therefore, such practice is the construction of concrete structures and the creation of impervious surfaces that reduce the infiltration capacity of city-landscapes to virtually zero percent [18].

Rainfall varies in intensity and duration, and so does the volume of rainwater that runs across the land. When rain is heavy, floods can result. No matter where you live – be it the tropics, the plains, the desert – floods occur. Within a human lifetime, everyone will have a flood pass near him or her. Within small drainage basins, brief, localized downpours can cause fast-moving but a short-lasting maximum flood. Everyone living near a stream needs to understand the frequency with which floods occur. Small floods happen every year or so. Large floods return less often – every score of years, century, or longer. Statistically speaking, the larger the floods, the longer is the recurrence times between each.

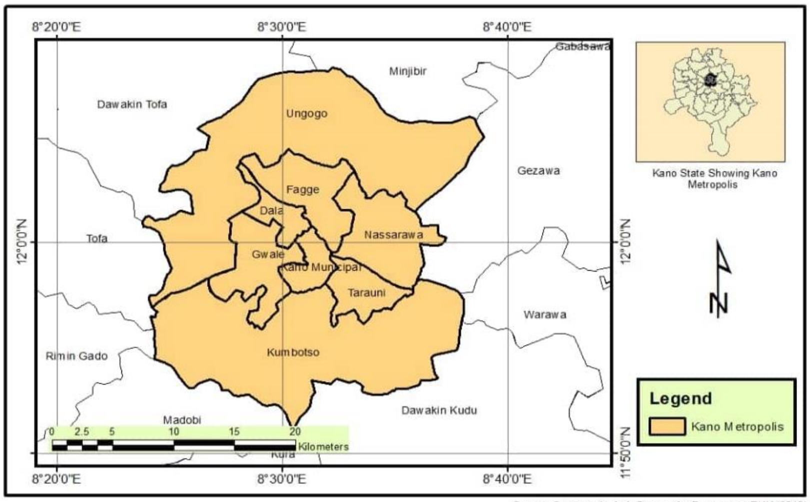
Human-induced flooding is the key figure in causing flooding in urban centers. An increase in population in an area especially a smaller one (urban) can make people erect buildings close to or on culverts or drainage systems. Apart from the increase in population, the lackadaisical behavior of government especially in developing countries causes and exacerbates the problem and has been regarded as a major creator of urban flood risk [19].

The research aimed to examine the human activity on the wise use of the environment and his readiness to flood within the metropolitan Kano. Understanding community readiness is important in such a way that people will come to know what they are supposed to do before, during, and after the incidence.

2. Materials and Method

2.1 Study Area

Kano Metropolis lies between Latitude 11^0 25'N and 12^o47'N and Longitude 08^0 22'E and 08^0 39'E. The Metropolis has eight LGAs i.e. Dala, Fagge, Nassarawa, Gwale, Tarauni, Kano Municipal, Kumbotso and Ungogo and is bordered by Minjibir LGA on the Northeast and Gezawa and Warawa LGA to the East, Dawakin Kudu LGA to the Southeast and Madobi and Tofa to the Southwest. It covers an area of approximately $500km^2$ (Figure 1).



Source: Cartography Lab Geography Department BUK (2018)

Figure 1. Map of the study area

2.1 Focus Group Discussion (FGD)

This research work employed both primary and secondary sources of data. Focus Group Discussion used as the primary source of data. Eight FGD were conducted; one in each local government area within Kano metropolitan. It consisted of 8-11 persons that include district head, ward councilor, representative of Local government Emergency Management Agency (LEMA), chairperson of community service in the area, trader doing their business at the area and other three to six stakeholders given by the community.

Reconnaissance surveys were made to district heads where flooding ever occurred in his custody as well as the environmental unit at the local government secretariat. The essence of this visitation was to introduce the topic and asked for gathering at least 8 to 12 people which should include; district-head, LEMA or environmental department representative, ward councilor, trader or business person doing his/her business close to the most affected area, chairman of community service in the area and other stakeholders selected by district-head. The researchers encouraged district heads to put females in their selection, as they are the ones mostly affected by flooding. Fagge, Kumbotso, Ungogo, Nasarawa put two females each in their selection. The phone calls were made within two weeks (9/2/2020 to 23/2/2020). For conducting FGD, the research team took different roles: one acted as note taker (and used recorder for recording), one acted as moderator while the other one was the observer of the general mood and body language of the participants. FGD have started between 10:05am to 11:37am (1/3/2020); 10:09 to 11:25am (2/3/2020); 5:32pm to 6:25pm (2/3/2020); 4:15pm to 5:28pm (5/3/2020); 10:02 to 11:34 am (6/3/2020); 11:00am to 12:35pm (10/3/2020); 11:10am to 12:13pm (11/3/2020); and between 2:58pm to 3:59pm in Gwale, Kano Municipal, Dala, Fagge, Tarauni, Kumbotso, Ungogo and Nasarawa respectively. For the analysis, FGDs were coded alphabetically; starting Dala and ended in Ungogo local government areas. All the FGDs took place at the district head's offices. There is mutual understanding between the research team and participants which makes the respondents answer questions freely both males and females, as they were sitting together.

The main reason for employing FGD in this research work is to involve people to explore what is the ground in their locality. On the other hand, secondary sources of literature include published and unpublished literature that is relevant to this research work. Thematic analysis was adopted where responses of the participants in FGDs were divided based on some thematic heading with a few questions under each thematic heading. The thematic headings were categorized into four: the relationship between flooding and NAMA prediction, causes of flooding, relief received from governmental agencies or non-governmental agencies (NGOs), and measures are taken to cope with flooding. The theme was a classified and coded letter to follow the theme of the presentation and compared with the field note taken during the session, views were gathered and interpreted based on the theme. This is because research uses the qualitative approach in analyzing data generated from FGDs. However, lessons from the aforementioned literature and theoretical frameworks together with the same experience used in developing questions under four major thematic categories.

Results and Discussion

The data collected through FGD, recordings were transcribed and coded based on three thematic headings. All long descriptions were discarded and focused mainly on the theme. The followings are the results of the discussions with focus groups.

There is unanimous agreement among all FDGs that climate change is among the causative agents of flooding in their areas. They responded by saying that in previous years they used to predict the amount of rainfall to be received based on the winter season, but now they cannot predict, as reported directly from the response of FGD in the Kumbotso local government area.

> *We used to predict the duration of the month we would receive rainfall based on the winter season. Because there is a correlation between the winter season and the rainy season in terms of length of months experience in the two seasons. Mostly, our winter season starts from November to February; that is four months. The same with rainy season is four months: May to September; but now we cannot predict due to fluctuation*

> *of winter and rainy season caused by climate change.- FGD 5*

Based on the finding of this research 75% of the respondents do not know the function of NAMA in predicting the amount of rain falling in an area. What they believe is that media stations broadcast weather forecasts mostly by them. However, even the forecast made by media stations on the amount of rain falling in a year is only 40 – 50% happen. For that, they do not believe media stations play a critical role in minimizing flooding. This negates the finding of Aderogba [17] which stated that media station in Nigerian media has been applauded by furnishing qualitative information regarding the widespread flooding in Nigeria. Only two local government areas (Fagge and Kumbotso) agreed that mostly they depend on NAMA on the amount of rain received every year through media stations.

While responding to questions on causes of flooding in their areas, it is stated by the respondents that, poor urban planning causes most of the flooding in Dala, Kano Municipal Nasarawa and Fagge local government areas. That is to say, there is poor urban planning not only in old Kano city but rather outside Kano city wall such as Dandinshe, Bridget, Fagge, Kurna. As one of FGD (Dala local government area) stated:

> *Akwai karancin tsarin layuka a wannan karamar hukumar saboda tsofaffin unguwannin da suke wannan local government. Wannan shi ne babban abin da yake jawo ambaliyar ruwa a wannan karamar hukumar kusan kowacce shekara. (There is a lack of urban planning in our own local government due to the old quarters it consists of. This is the main cause of flooding in this local government almost every year). - FGD 1*

This result is the same as what is in Fagge, Kano Municipal, Gwale and some parts of Nasarawa Ungogo. It is the same finding recorded in the work of Agbonkhese *et al.* [2] which found out poor urban planning causes most of the urban flooding in Nigeria.

Another cause of flooding mentioned by FGD in Kumbotso, Tarauni and Ungogo local government is that there is a lack of communal spirit:

> *Most people do not have a communal spirit. This means that most people engage in community activities are done if the environmental problem will affect their own dwelling. And at the same time, they have a misconception about the concept of 'environment'. People think that only their house is their environment. This makes them show 'I do not care' behavior. - FGD 7*

This lack of communal spirit recorded by some FGDs negates the finding of Vis et al. [20], which recorded that each person pays hundreds of Euros each year and takes the responsibility of flooding management as they have a communal spirit.

In Gwale, Fagge, Tarauni, Ungogo and Nasarawa FGDs there is a poor organization of community self-help groups. Almost all the community self-help groups are poorly organized. They only meet if there is an environmental hazard. They do not, most of the time, take preventive measures for flooding problems. They only organized after the first or second heavy rainfall. This poorly organized community self-help group leading them not even attempt to talk to the authority about what will be done to them before, during, and after flooding (if happened). This corroborates with the findings of Obeta [21] which indicated that stakeholders and community are poorly organized in tackling environmental hazards and take the hazard as momentary.

All FGDs discussed within Kano metropolitan local government unanimously agreed that there are inadequate tools to evacuate all refuse dumped at drainage such as containers, rain boots, shovels, wheelbarrows, hand gloves, rake, etc. this is a result of their poorly organization. According to some respondents in Dala, KMC, Ungogo, and Gwale identified that:

> *We have few instruments to clear our own gutters and culverts before the month of rain starts. Moreover, sometimes, the few instruments we have are always lost through borrowing from a member of that community as they are feeling they put their own share in purchasing these tools. - FGD 3*

According to all the respondents in all the study areas the major cause of the flooding is not climate change but rather a poor drainage and culverts. This according to them people erect structures in haphazardly except some parts of the Gwammaja ward. This is contrary to the finding of Agbonkhese *et al.* [2], which found out that climate change is among the causes of flooding in Nigeria.

On the people side, arbitrary dumping of refuse in waterways especially during the rainy season is among the causative agent of flooding. Respondents from Adakawa, Mazugal (Dala local government area), Diso, Mandawari (Gwale Local government area), Kurna and Fagge (Fagge local government area) dump their refuse in the waterways during the rainy season. This corroborated the result of [2], [22], which found out that a poor refuse disposal system is among the key causes of flooding in Borno.

The absence of dumping sites by the authority in most of the locality is a major reason because most of the respondents have the intention to dump their refuse in the designated area provided by the government. Nevertheless, unfortunately, local government provides little in some areas such as Ungogo, Mazugal.

Inadequate preparedness is considered by many respondents as the major cause of urban flooding in the Kano metropolitan. Contrary to what was used to practice to evacuate and clear all culvert and drainage before the rain starts falling. In line with this, Agbonkhese *et al.*, [2] identified poor preparation for the rainy season as among the factors that determine the flooding in Nigeria.

3.1 Relief (Assistance)

There is no relief received by our people during or after flooding by Non-governmental Organizations (NGOs) in all local government areas. For example, in the 2012-2020 floodings, no palliative given by NGOs received by victims or affected people in our local government areas. Non-governmental Organizations do not give anything economic support, but rather from our relatives and neighbors. To emphasize their view, here it is FGD result from Nasarawa local government which is almost the same as other local government areas within Kano metropolitan:

> *We do not receive any relief from any non-governmental organizations, but rather from our relatives and neighbors who provided clothes, food, mosquito nets, and sometimes money. We do not know if these NGOs give financial support to authorities like local governments. - FGD 6*

There is seldom give out palliative from the government, but there is discrimination in the distribution of such kinds of palliatives due to differences in political views as FGDs in Dala, Gwale, Kumbotso and Ungogo. This reported from FGD in Dala:

> *We receive some relief from the government after flooding depending upon the influence of your ward on the incumbent government especially we in Dala local government as you can compare with those in Kano Municipal where they receive full government support since they participate more in politics. - FGD 1*

This view is supported by all FGDs in Kano metropolitan, though there are differences in terms of the amount of support received from their relatives and neighbors. Those in Kumbotso, Kano Municipal, Fagge and Dala receive higher relief than those in the rest of the local government areas.

3.2 Measures/Disaster management plan

The disaster management plan includes a detail of the specification of equipment and machinery in plan. Similarly, planning is the plot, and hazardous areas classifications are map out; details of the risk assessment procedure adopted are also captured. Additionally, details of the on-site and off-site emergency plans are also required in the disaster management plan (Galatchi, 2005). As flooding is the most common disaster Nigeria experiences, Disaster Management Plan was used to see how preparedness the respondents are. Four stage disaster management cycle was used to see how people cope with the plan. These four stages are: preparedness, response, recovery, and mitigation.

3.2.1 Preparedness

This refers to the degree of alertness and readiness of an individual, a household, or a community against an upcoming disaster. Among many activities taken include providing hazard warnings, communicating with the public and others regarding disaster vulnerability, providing disaster training for emergency responders and the general public, just mentioned a few (Tierneyet, 2001). Almost all the measures taken are during or after flooding except in Dala, Kano Municipals, Gwale, Fagge and some parts of Nasarawa local government. The measures taking as mention by FGDs in clearing gutters and culvert a month before rain start. Tools such as a rake, shovel, hoe, and wheelbarrow provided together with food for the people to do such work. Nowadays, people liaise with REMASAB at the local government level to evacuate refused piled up along the gutter side.

3.2.2 Response

The response is referred to all activities conducted immediately before, during and after a disaster to save lives, minimize damage to property, and enhance the effectiveness of recovery in the shortest possible time [23]. Based on the result of FGDs all the FGDs identified that they participate hundred percent during flooding in rescuing and removing flooded water from entering rooms. One of the FGD in KMC quoted that:

> *Even if we did not prepare for flooding, when it happened, we do our best to rescue people and their properties; because everyone wishes to help. We sometimes create a path where flooded water can pass. - FGD 4*

3.2.3 Recovery

Recovery is a process of returning to a normal situation before disaster happen after a disaster has occurred. In this phase mostly increase in safety and future disaster preparedness are taken place here. This process includes interactive sessions and decision-making among different groups and institutions (both governmental agencies and NGOs), households, artisans, businesspersons, and the community at large [23]. Most of the urban flooding claims properties than lives.

The result of all FGDs indicated that there is no recovery phase taken by the community. They only focus on what happened. But there is one divergence in the opinion of FGD in Gwale and other FGDs. In the Gwale it is recorded that:

> *Immediately when flooding has taken place, we gather in our own community and discuss how to prevent such a disaster from the occurrence. However, this gathering is base on economic class. Within Gwale local government, rich men are gathering without inviting poor people or even district-head while in other areas only poor people struggle for taken recovery measures. Both rich and poor people leave their decision unimplemented up to the next rainy season. - FGD 3*

3.2.4 Mitigation

Mitigation activities actually eradicate or reduce the probability of disaster occurrence, or reduce the effects of unavoidable disasters. Mitigation measures include building codes; zoning and land use management; building use regulations and safety codes; preventive health care; public education, and so on. This phase is absent as reported by all FGDs:

> *This is the government's responsibility to make urban and regional planning, providing healthcare facilities, enforce the use of building regulation. - FGD 8.*

4. Conclusion and recommendation

This research identified that the functions of the National Emergency Management Agency (NEMA) were not known to the majority of people and the major causes of flooding such as lackadaisical behavior of people, lack of communal spirit, dumping of refuse in the gutter and culvert. The research work also showcased the relief when flooding occurred government and NGOs do not go to the hand of affected people if it is given. Based on the finding of this research work, the research recommended that Non-structural responses which include more accurate flood forecasting through the use of satellites and high-tech equipment, zoning and land-use policies, insurance programs, evacuation planning, and education should be adopted.

Authors Contribution

Ahmad Said Abubakar and Umar Abba design the topic and made literature survey on the subject matter. Nura Isyaku Bello, Abdulkadir Bello and Hassan Adamu partake fully in the course of data collection across the study area. All the authors contributed to the analysis of the data.

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