Proceedings of the 3rd Croatian Conference on Earthquake Engineering - 3CroCEE
19–22 March 2025, Split, Croatia

DOI: https://doi.org/10.5592/CO/3CroCEE.2025.110

ENGINEERING EXPERTISE ASPECTS DURING DISASTER RESPONSE – A CASE STUDY OF FLOODS IN FBIH

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Abstract

Heavy rainfall-induced floods, landslides and rockfall that befell Jablanica and Buturović polje regions in Bosnia and Herzegovina in October of 2024 caused widespread damage to buildings, roads, bridges, electrical, water supply and gas distribution networks, along with dozens of victims and hundreds of displaced people. Urban search and rescue operations started immediately, with international teams helping the local authorities and population in mitigating the destructive effects of the disaster. In this work, insights and experiences gained during rescue operations are synthesized and shared regarding behaviour of structures during floods and rockfall, including collapse mechanisms observed, damage to buildings, roads, bridges and infrastructural objects etc. Special focus is given to the unique challenges that floods and rockfall present in comparison with earthquake-induced disasters in terms of structural loads, damage patterns and collapse types, as well as differences in impact on terrain configuration, logistical needs and survivability of victims. While many differences are observed in terms of damage patterns in buildings and infrastructure, similar effects are observed when it comes to landslide and liquefaction occurrences. A review is given of the wide variety of typical tasks that engineers may face in areas affected by floods and rockfall, with attention to different tasks proper to structural, geotechnical, hydraulic and transportation engineers. While structural engineers may have a central role in urban areas after damaging earthquakes, in the case of floods and rockfall hydraulic and geotechnical engineering expertise becomes more important to understand the causes, scale and consequences of the disaster, while transportation engineering provides an important role of maintaining the functionality of roads and railways for efficient and safe disaster mitigation strategies.

Keywords: urban search and rescue, INSARAG, SET module, flash floods, damage assessment

1. Introduction – Roles of Structural engineering teams in disaster response

In the night of October 3rd to 4th 2024 at approximately 3 a.m. heavy torrential rain-induced flash floods, landslides and mudslides devastated the towns of Jablanica, Konjic, Kreševo, Kiseljak, Fojnica and Mostar municipality, causing widespread damage to buildings and infrastructure, taking 27 lives and displacing over 300 people. Over 1000 households were affected by the event, out of which an estimated 55 residential houses were completely destroyed, while more than 800 have been reported damaged [1,2]. The town of Donja Jablanica was affected the most, as the flash flood encountered a defunct quarry in the area above the town and induced a rockfall, causing additional devastation. Alongside residential houses, critical infrastructure has also been damaged in the wider affected area (bridges, roads, railways, electrical grid, water supply etc.), causing additional logistical challenges in the first responder phase, as well as additional requirements in the relief phase.

The Federation of Bosnia and Herzegovina (FBiH) declared a state of national emergency on October 5th 2024, and the European Union Civil Protection Mechanism (EUCPM) was activated. Among other first response capacities deployed through the mechanism, urban search and rescue (USAR) teams from Croatia, Slovenia, Serbia and Montenegro have been deployed. The Croatian USAR team consisted of 37 members and 2 rescue dogs. The team composition included 2 structural engineers of the Croatian Centre for Earthquake Engineering – Intervention Service (HCPI – IS), the authors of this reconnaissance report. The mission lasted from deployment on October 5th until demobilisation on

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October 11th 2024 when most international USAR teams concluded their work and relief phase was initiated.

The specific roles of structural engineers during disaster response operations are a topic of great importance for HCPI – IS as it is a relatively new addition to the Croatian civil protection capacities on the national level, having been established as a result of the key role that structural engineers had during the response to earthquakes in Zagreb and Petrinja in 2020 [3]. The new intervention unit has been fruitfully incorporated into the Croatian civil protection system with the goal of implementing all available structural engineering knowledge in any disaster situations by combining both contemporary scientific research, practicing engineering knowledge and experience to mitigate the consequences of such disasters.

Currently, the Croatian Structural Engineering Team (SET) is in the process of EU certification as an Other response capacity (ORC) within the EUCPM [4], with the capacity to carry out building damage, safety and usability assessments on a large scale, appraisal of buildings to be demolished or repaired, assessment of critical infrastructure, short-term shoring of damaged buildings and assistance to USAR teams in assessment of collapsed buildings. Half the team consists of HCPI – IS engineering experts, while the other half consists of members of the Civil Protection – State intervention unit (DIP CZ) providing technical and tactical support (TAST), logistics and on-site support.

This report aims to analyse the tasks required of the structural engineers that were part of the Croatian USAR team during the mission in FBiH, identify key roles of structural engineering experts in disaster response (particularly in the first responder phase) and recommend further steps within the engineering aspect in order to better prepare the SET module for international deployment.

2. Assessment of collapsed buildings – assisting USAR teams

The most severe structural damage was documented in Donja Jablanica (Fig. 1), with residential buildings primarily consisting of masonry structures of varying construction quality. Older homes were built with stone masonry or earthen walls, whereas newer houses primarily used hollow clay brick, sometimes incorporating reinforced concrete tie beams. Most houses numbered one or two stories with a semi-buried basement. The roofs were typically wooden and often in a deteriorated condition.

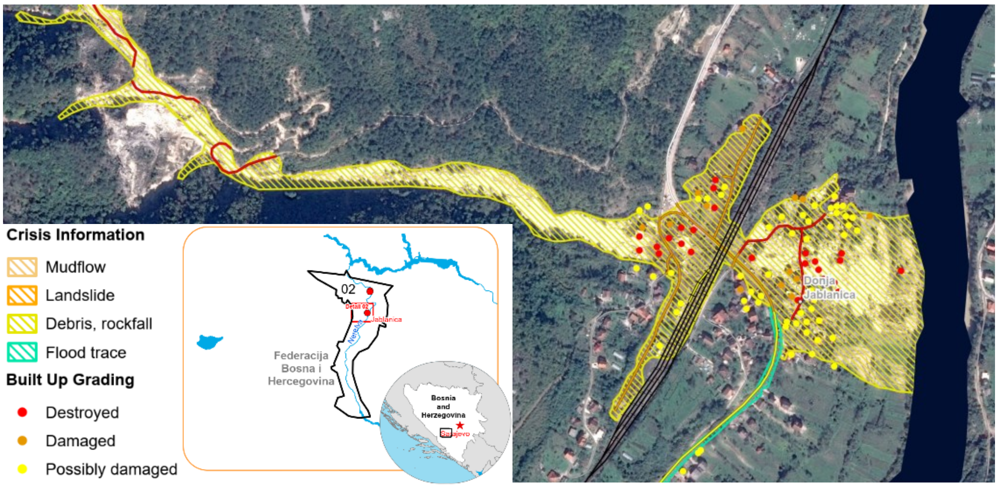

Figure 1. Copernicus emergency management service satellite image of the affected area in Donja Jablanica (source: Copernicus EMS, EU)

The floodwater and rockfall subjected buildings to extreme lateral forces, both from the impact of dislodged boulders originating from a defunct quarry and the stationary dynamic pressure of the flash flood [5]. Structural failure mechanisms varied. In some cases, shear failure at the RC foundation level led to the displacement of entire buildings above the foundation over distances of up to 100 meters. Where foundations were weak or shallow—often consisting of stone or poorly compacted soil—entire

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structures collapsed, with individual building elements carried away by the water current, making identification of original structures difficult. Total structural collapse, where individual elements became fully detached and unrecognizable, can be classified under the *debris heaps* collapse type according to INSARAG (International Search and Rescue Advisory Group) worksite triage categories [6] used by USAR teams for designating potential worksites. Partially collapsed buildings that remained on-site could also be classified under INSARAG as either *debris heaps*, where collapsed structures shifted onto adjacent parcels, or *overhanging elements*, where partial ground-floor collapses left upper floors cantilevered, posing a significant risk of secondary collapse (Fig. 2). Other INSARAG collapse types (*overturning, pancake*, and *inclined layers*) were not observed in Donja Jablanica.

a)

b)

Figure 2. INSARAG collapse types observed in Donja Jablanica; a) debris heaps, b) overhanging elements

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The observed collapse distribution significantly deviates from that of seismic events, such as the 2023 Türkiye earthquake, where *pancake* collapses and overturning of RC frame structures were predominant [7]. Furthermore, the damage patterns of individual elements differed from those typically seen in earthquake-induced failures. No diagonal shear cracks were observed in masonry walls, as these are characteristic of seismic loads. Instead, geotechnical effects, including differential settlement and horizontal cracking, were the primary structural response mechanisms.

In addition to structural failures, widespread infrastructure displacement posed further hazards. Numerous streetlights, electrical poles, retaining walls, and fences were visibly leaning, posing an ongoing risk of overturning. Energy infrastructure was heavily damaged, with displaced electrical cables increasing the risk of electrocution and possibly ruptured water supply pipes raising contamination concerns. Flood debris entered the basements and garages of all houses in the affected area, consisting of a complex mix of materials, including large quarry boulders, stone, sand, gravel, clay, mud, and structural timber fragments, which posed worksite hazards to be avoided during search and rescue operations. The floodwaters ultimately deposited a significant volume of the debris into the Neretva River, raising concerns about sediment accumulation at a dam downstream. A comprehensive risk assessment of the downstream dam's structural integrity requires hydraulic engineers to analyze sediment deposition, potential scouring, and hydrodynamic loads on the structure.

Given the scale of structural collapse, heavy machinery—primarily excavators—played a critical role in clearing debris and assisting in search operations. Structural engineers provided guidance on safe removal of unstable elements. One instance involved lifting a collapsed RC floor to check for survivors, illustrating the effectiveness and practicality of excavators as a short-term shoring solution, especially for medium USAR teams which do not feature their own heavy machinery.

Structural engineers played a critical role in assessing the stability of collapsed buildings and advising on safe search and rescue operations, particularly in mitigating risks associated with secondary collapses, especially in structures where detached roof beams, fractured concrete elements, and freestanding walls or facades remained precariously in place. On the other hand, the complexity of soil movement, landslide and mudslide effects and foundation failures highlighted the necessity of geotechnical expertise in disaster response. Furthermore, a risk assessment of the dam downriver is a task best suited to a hydraulic engineer. The absence of geotechnical and hydraulic engineering specialists on-site limited the ability to fully assess ongoing ground stability risks, particularly in areas prone to further landslides. Integrating specialised engineering assessments alongside structural engineering evaluations into USAR teams would provide a more comprehensive approach to post-disaster reconnaissance, ensuring both immediate responder safety and long-term stabilization of the affected areas.

3. Structural reconnaissance – UAV techniques

The reconnaissance efforts extended to Buturović Polje, a smaller settlement located along a river bend in the area of Jablanica Lake (Fig. 3), characterized by soft sediments. The flash flood significantly reshaped the terrain, eroding an entire stream branch that once extended to the bend and broadening the channel. The flood impact was not confined to Buturović Polje. Upstream settlements, including Trusina, also suffered significant damage, contributing to the mass of debris that was deposited through Buturović Polje into Jablanica Lake.

Several houses were swept away by the flood, while others sustained severe damage, with predominantly overhanging elements collapse type patterns similar to those observed in Donja Jablanica. Victims were carried downstream, buried in mixed debris composed of wood, soil, mud, and other materials. The search for survivors was conducted through a combination of ground teams searching along the riverbanks, water rescue teams using dry suits to navigate the river, and aerial reconnaissance utilizing UAVs (unmanned aerial vehicles).

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a) b)

Figure 3. a) Copernicus emergency management service satellite image of the affected area around Buturović Polje (source: Copernicus EMS, EU); b) photograph of the reshaped terrain along the river bend

While primary responsibilities of structural engineers were limited in this non-urban area, an opportunity arose to evaluate the UAV-assisted search operations techniques. UAVs designed for large-area reconnaissance are valuable to SET modules for broad assessments, especially in the initial phase of sectorization of the affected area. They offer advantages such as joystick-based control interfaces that provide intuitive maneuverability over broad landscapes, longer range and better battery life. However, they could prove less effective for the specific needs of structural engineers when assisting USAR operations, as they cannot inspect the interior of buildings [8]. Instead, the deployment of smaller UAVs with enhanced maneuverability appears as a more viable option (Fig. 4). Such UAVs, equipped with headset controllers, enable precise navigation within confined spaces and allow for structural reconnaissance of the interiors of partially collapsed buildings, providing real-time assessments of internal structural conditions without requiring personnel to enter unsafe areas. This approach would enhance responder safety while improving the accuracy of damage assessments in future urban disaster scenarios. Consequently, integrating both large-area reconnaissance UAVs for sectorization and assessment purposes and compact, high-maneuverability drones for evaluating structural integrity into SET modules could improve operational efficiency and safety assessments in structural reconnaissance efforts.

a) b) c)

Figure 4. a) A large debris-filled area of the Jablanica Lake for large-area reconnaissance; b) Joystick-controlled UAV for large area surveillance; c) Light UAV with a headset controller for building interior reconnaissance

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4. Critical infrastructure assessment

4.1. Access roads

The roads between the locations where our team was deployed were severely impacted by the flash floods, with debris such as rocks, soil, and vegetation obstructing the roadways. Many embankments and roadbeds were displaced by landslides, and in some cases, the roadway was washed away, rendering it impassable. Damage to the pavement surface included Longitudinal cracking of pavement surface and settling of the road edges has been observed (Fig. 5). The priority of the local authorities was to maintain road access, and by the time our team arrived, all main routes had been cleared, although they remained in a compromised condition. This rapid restoration of access was critical, as it enabled the continuation of emergency operations and evacuation efforts. However, the provisional routes were susceptible to further landslides, particularly in the context of anticipated rainfall.

Figure 5. State of the roads in the affected area connecting the main disaster sites

These conditions highlight the importance of transportation engineering expertise in post-disaster assessments, especially as part of a SET module. Transportation experts can evaluate road stability for heavy vehicle use, provide timely and accurate assessments of road conditions, guide the establishment of safe alternative routes, and recommend necessary repairs or reinforcements. Including transportation engineers in SET modules is crucial to ensuring the safety and efficiency of disaster response operations and supporting the host nation's recovery efforts.

4.2. Bridges

Local authorities requested our USAR team to dispatch structural engineers to assess three road RC beam bridges between Buturović Polje and Jablanica (Fig. 6). These bridges were suspected of instability due to erosion and landslides, which had washed away substantial material beneath the bridges and altered the terrain around the foundations of the piers. Despite these concerns, traffic continued to flow across the bridges, making it crucial to ensure that the flow remained safe and uninterrupted, as these are key transportation routes in the area.

Our inspection indicated that the piers were founded on piles extending to bedrock, with adequate anchorage. This conclusion was supported by the absence of visible displacement or damage to the pile caps, as well as to any other structural elements of the bridges, including the pavement surface. Based on these observations, we recommended verifying the pile length and depth from the original construction drawings. Additionally, a geotechnical expert should be engaged to assess the stability of the soil beneath the foundations, with subsequent recommendations for reinforcing measures, if necessary, to ensure the long-term safety and functionality of the bridges.

It is essential to underscore the importance of critical infrastructure assessment, which requires specialized knowledge and expertise. While this case pertains specifically to bridges, the same principles apply to other critical infrastructure such as hospitals, schools, and utilities. In this instance,

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our field engineering team benefited from support provided by our HCPI–IS headquarters in Croatia, where bridge specialists were available to offer guidance and advice. This collaboration highlights the necessity of including a small team of experienced engineers in each mission, ready to provide additional support from the home headquarters when needed. Such a team can gather information from broader sources concerning the affected area and assist field teams with relevant insights, enabling them to better prepare for potential challenges on the ground. This approach has proven invaluable in previous missions as well [7].

Figure 6. Photographs of key structural elements of the inspected bridges and the eroded terrain in the area of pier foundations

Regarding the SET modules, it is crucial to incorporate one or two teams of critical infrastructure experts, consisting of experienced engineers, to ensure that accurate assessments can be made in the field. Critical infrastructure evaluation is one of the top priorities during the early response phase of any disaster. As demonstrated in this case, the host nation may not always have the capacity to conduct these assessments promptly. Therefore, the presence of critical infrastructure specialists is one of the most effective ways to support the host nation and ensure a rapid and informed response.

5. Conclusions – engineering expertise in disaster response operations

An overview of different structural engineering activities during search and rescue operations in the initial response phase after the flash floods of 2024 in Bosnia and Herzegovina has been given in this work. These activities have been conducted by a team of structural engineers that were a part of the Croatian USAR team operating in the affected area. The different engineering aspects have been highlighted in light of a new Croatian Structural engineering team (SET) that is currently in the process of EU certification as an other response capacity (ORC), aiming to offer engineering knowledge, expertise and experience to mitigate the consequences of major natural disasters both domestically and internationally.

The mission in Bosnia and Herzegovina demonstrated the critical role that specialized engineering expertise plays in different disaster response phases. Structural engineers play an important role in ensuring safe and efficient work of USAR teams, but engineering expertise can be offered beyond USAR operations as well. Structural engineers, transportation experts, hydraulic engineers, geotechnical specialists and critical infrastructure assessment experts are all integral to a SET module, each contributing unique insights essential for the rapid and safe assessment of disaster-affected areas. Mission experience underscored the importance of including experts in each of these fields to address a broad range of post-disaster challenges, from assessing collapsed structures and critical infrastructure to evaluating the stability of roads, bridges and soil. The opportunities for using various types of unmanned aerial vehicles (UAVs) in different stages of disaster response have also been explored, both for initial sectorization of large urban areas and enhancing building damage assessment in closed interior spaces.

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Incorporating these diverse engineering roles into SET modules provides a robust framework for effective application of engineering expertise in the aftermath of major disasters. It ensures that not only immediate safety concerns are addressed in the first response phase, but also long-term recovery strategies are effectively planned in the relief phase. The interdisciplinary approach outlined and proposed here strengthens the overall response capacity by offering crucial support to the host nation's efforts both in the critical early response phase and in the long-term.

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