Detailed Study Report on Rainfall induced disaster in the district of Mandi, Himachal Pradesh

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Introduction:

Between June 29 and July 25, 2025, the Mandi district of Himachal Pradesh endured a devastating spell of extreme rainfall that led to flash floods and landslides, resulting in significant human and infrastructural losses (Pandey & Satyam, 2026). Triggered by a series of cloudbursts and sustained heavy rain, the disaster has taken a heavy toll on the region, with at least three lives lost, one person injured, and another still missing. Torrents of water inundated residential areas, submerged homes, and buried over 20 vehicles under debris. Roads, including key national highways, have been rendered impassable, and basic utilities such as electricity and water supply have been severely disrupted, particularly in areas like Jail Road, Saini Mohalla, and the vicinity of the Zonal Hospital.

The India Meteorological Department had issued an "orange alert" ahead of the disaster, warning of intense rainfall in the region. Mandi recorded its highest rainfall figures of the season on July 1 and July 29, with 217 mm and 199 mm respectively, both of which played a critical role in triggering flash floods and landslides. Emergency response teams, including the NDRF, local police, and home guards, swiftly launched rescue operations, evacuating around 15 to 20 people and setting up a relief camp at Vipasha Sadan. Meanwhile, departments such as Public Works, Jal Shakti, and power utilities are working to clear debris and restore essential services. Professor Neelima Satyam, as part of the evaluation committee, visited the affected sites to assess both the causative factors and the efficiency of the disaster response mechanisms. With the monsoon causing over ₹1,539 crore in damages across Himachal Pradesh so far, this incident underscores the escalating vulnerability of the region to climate-induced disasters, despite existing preparedness plans by the local disaster management authorities.

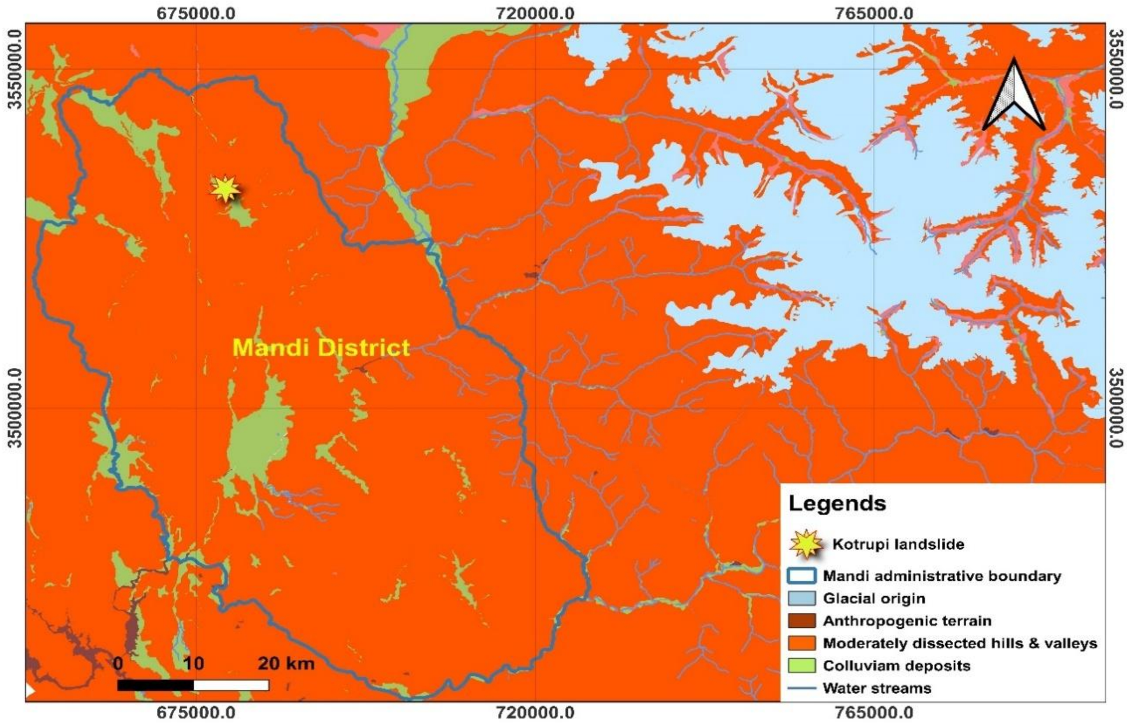

Fig:1 Geomorphology of Mandi district (Pandey et al. (2024))

Geomorphology and Geology of Mandi

Following the initial assessment of the rainfall-induced disaster, our team conducted a detailed examination of various regions across the Mandi district. The geomorphological setting, as illustrated in Figure 1 and elaborated by (Pandey, Satyam, et al., 2024), reveals that Mandi is composed of dissected valleys and hills, interspersed with deposits of colluvium. These geomorphological features, coupled with intense rainfall events, have contributed significantly to slope instability, making the region highly vulnerable to flash floods and landslides. The interplay between topography, soil cover, and hydrological dynamics plays a critical role in influencing the spatial distribution and intensity of such disasters.

Mandi's geological and topographical complexity is notable. The district lies within the geologically diverse landscape of Himachal Pradesh, encompassing the Shivalik ranges, Lesser Himalayas, and prominent intermontane valleys like the Balh valley. Its terrain is shaped by ancient Precambrian rocks, volcanic deposits, and sedimentary formations such as dolomite, limestone, quartzite, and red shales. The Shah Formation, characterized by salt grit and various sedimentary layers, and the Mandi-Darla volcanic formation with evidence of past lava flows, underscore the tectonic and volcanic history of the region. Mandi is encircled by mountain ranges such as Gandharv Hills, Motipur Dhar, Rehra Dhar, and Tarna Hill, forming a bowl-like depression that channels rainfall runoff. The district's altitude varies dramatically, from 550 meters near Sandhol to nearly 3960 meters near the Kullu border, intensifying the vertical relief and enhancing the landslide risk. The presence of the Beas River, which meanders through the region, further amplifies hydrological loading during periods of intense rainfall, contributing to slope failures. Recognizing this, landslide susceptibility maps have been developed and utilized for risk assessments and disaster preparedness planning.

Preliminary site visit

To assess the extent and nature of the disaster, we conducted detailed field visits to seven critical locations across the Mandi district, each selected based on reported severity and diversity in the type of geomorphic failures. These sites included: Location 1 – Sarkol Nala failure (31°24'06.0"N, 77°11'06.0"E), Location 2 – Shankar Dera failure (31°25'39.4"N, 77°11'58.5"E), Location 3 – Janjehli failure with significant boulder movement (31°30'24.6"N, 77°12'46.0"E), Location 4 – Pandav Shila, Location 5 – Siraj Government College, where the ground floor was buried under 5–6 feet of debris on the night of July 30, Location 6 – a site at 31°32'08.8"N, 77°09'31.7"E showing a granular flow with large boulders in an engineered gully, and Location 7 – Thunag, which experienced the maximum failure among all surveyed areas.

Data collection at each of these sites was undertaken through both physical inspection and technological support. Assisted by committee members and a specialized technical team, we deployed drones for high-resolution aerial mapping (Figure 4), while detailed ground observations and documentation were conducted in parallel (Figure 3). These combined efforts allowed us to capture the spatial characteristics, material composition, and movement patterns of the failures with high accuracy. Based on our initial assessment and drawing upon the conceptual framework proposed by Yanites et al. (2025), we observed that the events in Mandi represent a classic case of multiple cascading hazards. This process begins with prolonged or intense rainfall, which triggers initial slope failures. These landslides often evolve into granular or debris flows, which subsequently obstruct river channels, forming temporary dams and compounding the downstream risk. This chain of interconnected geomorphic processes effectively illustrates the systemic nature of mass movements that unfolded in the district (Figure 2).

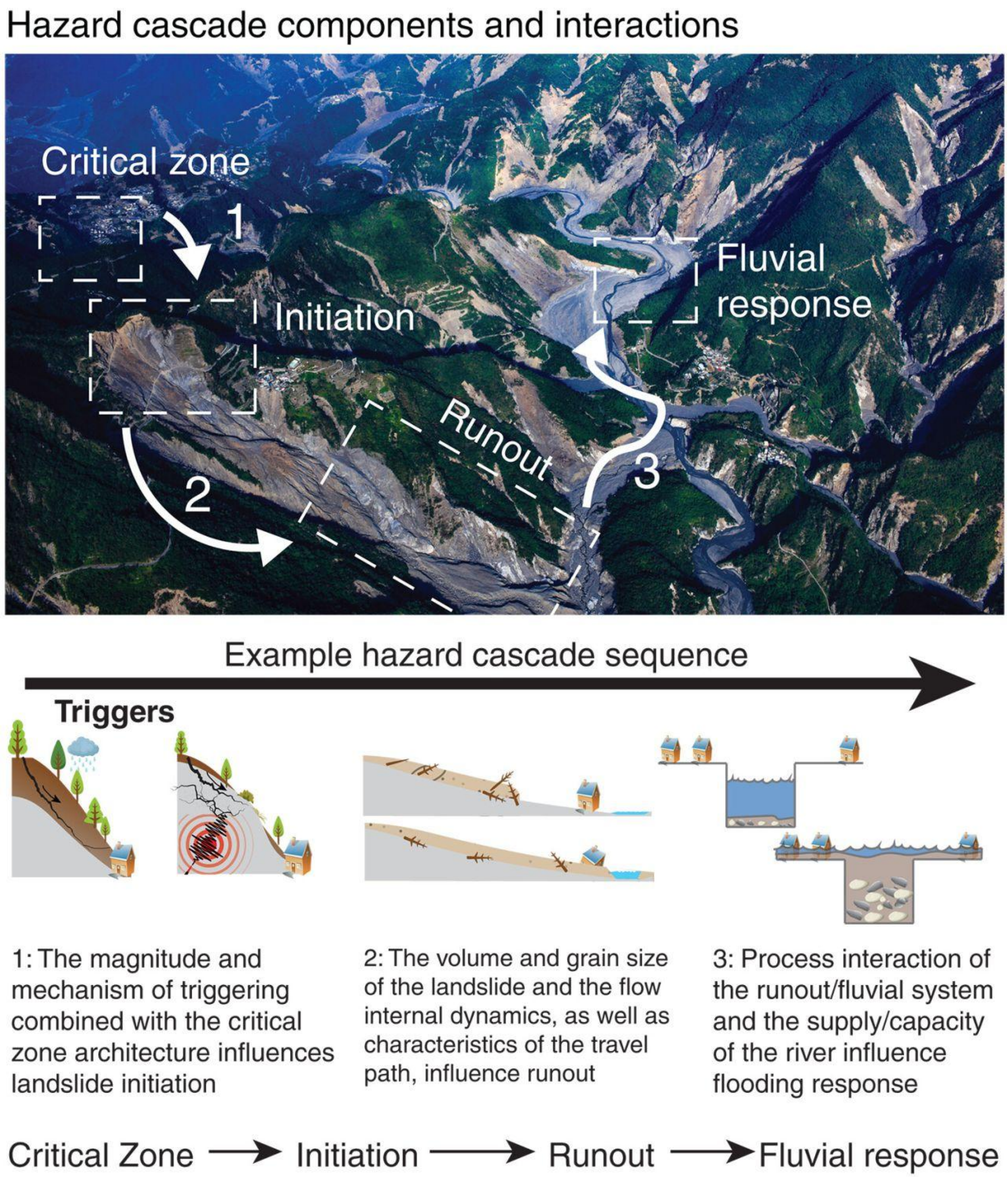

Fig:2 Schematic events unfold during cascading events (modified from Yanites at el. 2025)

Fig:3 Visiting committee members in the affected areas

Mandi District – Geology & Soil

- Lithology: Shales, sandstones, slates, and limestone, from the Siwalik Group and Sub-Himalayan Series.
- Tectonics: Also lies in the Outer Himalayas with several active faults; prone to deep-seated land subsidence and slope failures.
- River Erosion: The Beas River and its tributaries cut through soft formations, causing lateral erosion and undercutting of slopes.

Fig:4 Expert team involved in drone mapping of affected area

Observations

Building upon the field investigation and visual documentation, each of the seven surveyed sites revealed a distinct pattern of geomorphic response to the extreme rainfall events. The nature of mass movements varied based on local geomorphology, vegetation cover, channel dynamics, and the extent of anthropogenic interference. Figures 5 through 12 present photographic evidence and mapped interpretations of these failures, aiding in the assessment of processes involved.

Location 1: Sarkol Nala (Fig. 5)

This site primarily exhibited dry granular flow, with minimal presence of fines or saturated slurry. The failure here was dominated by mechanical entrainment and downslope movement of colluvial material. Scrapping of surface layers exposed bedrock, while the gully system served as the main transport path. There was little evidence of cascading processes; the flow was mostly limited to a single-stage event. Figure 5a shows the exposed bedrock surface due to scouring, while 5b highlights entrainment of material within the narrow gully system.

Fig:5 Granular flow in Sarkol Nala a) Scrapping and exposed bed rock b) entrainment over the gulley

Location 2: Shankar Dera (Fig. 6)

At Shankar Dera, the interaction between mass movement and vegetation was significant. Uprooted tree trunks, broken roots, and other organic debris blocked multiple culverts, suggesting a prominent flow-structure interaction. This led to the redirection and accumulation of flow, aggravating the failure. The presence of both debris and flowing water suggested partial saturation. Figure 6a depicts the uprooted vegetation, and 6b illustrates the blockage of the culvert, which contributed to local flooding and terrain instability.

Fig:6 Landslide in Shankar Dera a) uprooting of vegetation b) blockage of culvert due to flowing trunks/roots of vegetation

<u>Location 3: Janjehli (Fig. 7)</u>

This area demonstrated a typical cascading scenario, where coarse particles, including large boulders, were transported and deposited across dry and semi-active gulleys as well as into the riverbed. The interaction of dry flow over existing channels suggests intermittent flow activation. Exposed bedrock and the collapse of multiple houses were observed in the deposition zone. Figure

7a captures the rocky terrain and mobilized boulders, while 7b shows the remnants of housing structures buried in debris.

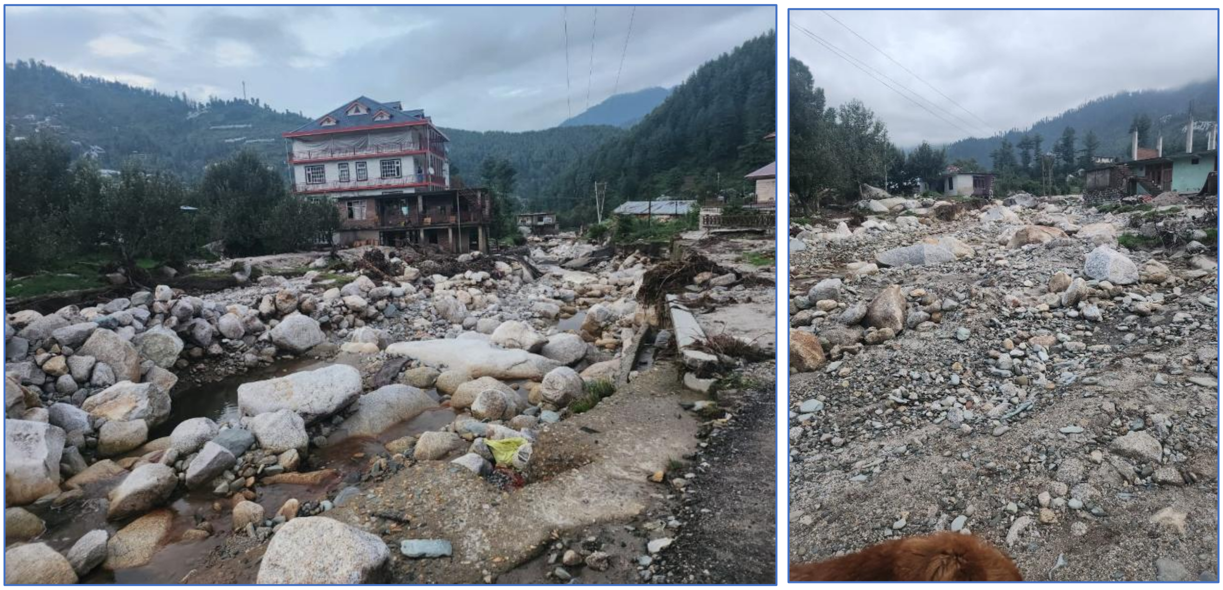

Fig:7 Landslide in Janjehli a) exposed bed rock with big boulders and rocs b) multiple houses collapsed with left out deposition of debris over bed

Location 4: Pandav Shila (Fig. 8)

In Pandav Shila, the failure included riverbank erosion and a strong flow-structure interaction. The mass movement here dammed the local river and destroyed nearby homes, primarily due to the impact of boulders within the debris striking built structures. This is another instance of cascading failure, where an initial slide evolved into a debris flow that altered the river course and intensified destruction. Figure 8a shows the eroded banks, and 8b presents the collapsed structure impacted by the flow.

Fig:8 Landslide in Pandav Shila a) Eroded banks b) Flow-Structure interaction caused house collapse

<u>Location 5: Seraj College (Fig. 9)</u>

This site is particularly notable for the significant human vulnerability involved. The debris flow here not only dammed the river but also led to the accumulation of 2–3 meters of debris around institutional infrastructure, submerging parts of the Seraj College building. The location of schools and colleges in high-risk zones exacerbates the hazard. Figure 9a shows the blockage of the river channel, while 9b displays the building partially buried in slurry and debris.

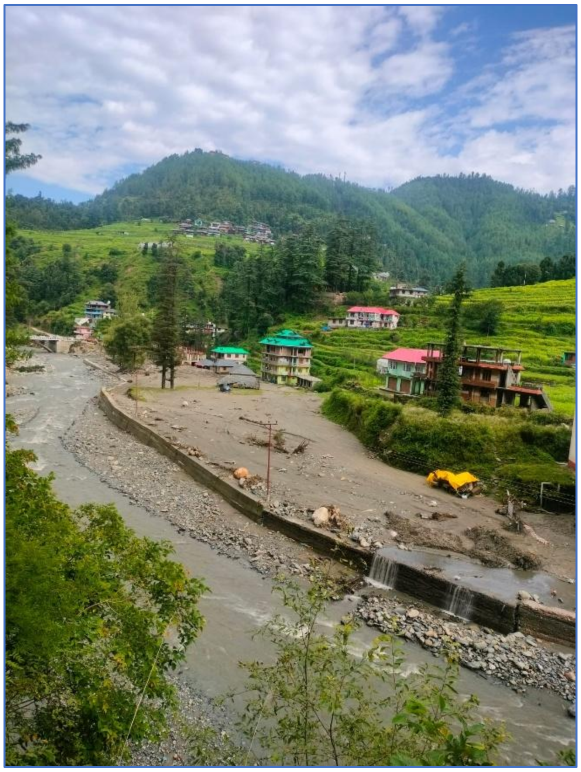 

Fig:9 Landslide near Seraj College a) Debris flow damming river channel b) College building submerged with debris/slurry

Location 6: Near Bharad (Fig. 10)

Here, the dominant feature was the presence of large boulders within drainage channels and granular flow deposition in engineered gullies. The debris blocked channels and suggests a process involving dry granular flow with minimal fluid content. The event involved a sudden release of material into man-made gullies, which likely failed due to poor design or inadequate drainage capacity. Figures 10a and 10b highlight the massive boulders and the clogged engineered gulley.

Fig:10 Landslide near location 6 a) Big size boulders present in drainage channels b) Drainage gulley is dammed with granular flow

Location 7: Thunag Valley (Figs. 11 & 12)

Thunag represented the most complex and severely affected site, characterized by multiple overlapping processes like landslides, debris flows, bank erosion, and river damming which is occurring in close sequence and spatial proximity. This is a textbook case of a cascading geomorphic event, where each process fuelled the next, resulting in extensive landscape transformation and infrastructure damage. Figures 11 and 12 capture the progressive failure sequence, with river blockage, redirected flow paths, and significant debris deposition along both natural and built environments.

Fig:11 Landslide near Thunag Valley, multiple cascading events led to erosion and deposition of debris along the bank and built-up area nearby

In summary, the field observations and supporting imagery confirm that while some events were localized or limited in scale, others especially in Janjehli, Pandav Shila, and Thunag have demonstrated the characteristics of cascading hazards. These include sequential triggering of different types of mass movements, interaction with infrastructure, and amplification of damage due to landscape configuration and human settlement patterns. This complexity emphasizes the need for site-specific risk assessment and stricter land-use controls in sensitive zones.

Fig:12 Landslide near Thunag Valley caused river damming and bank erosion

Brief analysis

The July 2025 Mandi rainfall-induced disaster exemplifies the growing prevalence of cascading geomorphic events in the Western Himalayas, where a single trigger—such as intense rainfall—leads to a sequence of interconnected hazards, including landslides, debris flows, and river damming. Based on our field investigation across seven critical locations and supported by drone surveys and physical inspections, it is evident that this event cannot be classified under a single failure type. Instead, using the JTC1 Landslide Classification (Hungr et al., 2014), the Mandi disaster spans multiple categories: *debris slides, debris flows, debris avalanches, landslides,* and *mudflows*. This diversity in failure types is a direct result of the region's geomorphology, particularly the abundance of unconsolidated colluvial material, which becomes highly mobile when overlain by intense surface runoff caused by flash floods.

Rainfall intensities approaching 200 mm/day, as recorded on July 1 and July 29, far exceed Mandi's drainage and slope stability thresholds. These extreme precipitation events, combined with poor drainage and fragile geology, have exposed significant gaps in disaster preparedness. The presence of built-up structures especially residential buildings and educational institutions, on drained riverbeds or vulnerable slopes further amplified the impact. As observed in locations like

Seraj College and Pandav Shila, human settlements placed in hazard-prone areas suffered the worst outcomes, often due to *flow-structure interactions* and riverbank erosion.
The failures also demonstrate an important regional distinction: the high content of coarse particles and boulders in the debris (Pandey, Singh, et al., 2024). In contrast to similar events documented in Italy, China, or the USA, where finer material dominates (Gong et al., 2023), the Western Himalayan debris profiles involve large rock fragments capable of devastating impact forces, often resulting in total building collapse. This observation reinforces the need for region-specific mitigation strategies, including the construction of engineered barrier systems near vulnerable settlements, regulated land-use planning, and strict enforcement against unplanned construction on floodplains or former riverbeds.

Furthermore, the unpredictability of deposition patterns in such mountainous terrains requires a revised approach to settlement planning. Instead of linear or ribbon development along slopes and rivers, conical settlement models in broader, relatively flat valleys could reduce exposure. Drawing lessons from past disasters like Kotrupi (2017) in Mandi, it is critical to implement a regional mitigation and resilience framework tailored to the unique geomorphological and climatic realities of the Western Himalayas.

Annexure

Location	Coordinates	Type of Failure	Dominant Process	Probable Cause
1. Sarkol Nala	31°24'06.0"N, 77°11'06.0"E	Dry granular flow; minor landslide	Scraping, entrainment of colluvium	Intense rainfall loosened surface colluvium; dry flow moved through gullies without major water saturation. Minimal cascading.
2. Shankar Dera	31°25'39.4"N, 77°11'58.5"E	Landslide with debris flow	Flow-structure interaction; culvert blockage	Vegetation and tree trunks obstructed culverts, leading to local water impoundment and failure; interaction with built drainage.
3. Janjehli	31°30'24.6"N, 77°12'46.0"E	Cascading landslide and boulder flow	Boulder runout, saturated and dry channel flows	Combination of dry and wet flows in active and inactive drainage channels; coarse debris caused structural collapse.
4. Pandav Shila	31°32'12.87"N, 77°12'40.02"E	Landslide, debris flow	River damming, flow-structure interaction	Debris flow with boulders blocked the river, redirected flow toward settlements, causing destruction of houses.
5. Near Bharad	31°32'46.06"N, 77°12'40.43"E	Debris slide with granular flow	Boulder movement in engineered gulley	Oversized debris overwhelmed engineered structures; dry flow with poor water escape led to blockage.
6. Seraj College	31° 33'28.8" N, 77°11'28.32" E	Debris flow and river damming	River channel blockage; structural impact	Presence of buildings in vulnerable floodplain; 2–3 m deposition due to debris damming and spillover.

7. Thunag Valley	31°33'30.06"N, 77°9'56.53"E	Multiple cascading landslides	Landslide, debris flow, erosion, damming	Chain reaction of failures due to intense rainfall: initial landslide triggered debris flow and river damming; high impact on nearby infrastructure.

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