The physics and psychology of stampedes

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Shoes are pictured where a stampede killed 121 people during a sermon at Hathras in Uttar Pradesh on July 3 (AFP FILE)

NEW DELHI: In many ways, what happened in Hathras on July 2 was typical of other deadly stampedes over the decades. The trigger itself may be unique to each stampede; in Hathras, the first people who stumbled had bent to pick up sand stepped on by the baba whose event they had gone to attend. What followed, however, has been common to many other stampedes: individuals slipping and falling (wet ground has contributed to previous stampedes too), then panicking, jostling and falling over one another while looking for elusive exit routes in a crammed area.

The study of stampedes, which has picked up in recent decades, involves a lot more than the psychology of people moving haphazardly in a panic. More precisely, it is the study of crowd dynamics, of which stampede events are an inevitable part, that has become a diverse field today with lessons to offer, partly because of the modern tools available to computer modelling, and largely because understanding crowd behaviour can lead to preventive measures against high-risk events, particularly stampedes.

'Black hole' in a stampede

In many stampedes, possibly including the one in Hathras, deaths occur as a result of a phenomenon that researcher Dirk Helbing describes as the "black hole effect". Helbing, a professor of computational social science at ETH Zurich, is a leading global expert on crowd dynamics; his analysis of Haj crowds following a stampede during the 2006 pilgrimage, which caused 362 deaths, led the authorities to introduce new control measures, particularly in Mina.

Helbing describes the "black hole effect" in a 2014 paper in the Journal of Statistical Physics. When people are moving in a tightly packed crowd, the contact between their bodies causes physical forces to be transmitted from one individual to another. These forces may add up and create unpredictable "force chains" pushing the individuals from various directions. Eventually, these pushes may reach a level that can cause one or more individuals to stumble and fall.

Such a fall, in turn, creates a "hole" in the crowd. This breaks the balance of forces among the surrounding people: they are still being pushed from behind, but no longer from the front because of the "hole".

"Therefore, people in the neighbourhood tend to lose their equilibrium and fall also. Consequently, people will be piled up. Those on the ground suffer from the weight [of other individuals] and have difficulty breathing," Helbing told HT. He believes this is more or less what happened in Hathras, going by what he has seen in videos after the incident.

The dynamics of crowds

Identifying such factors comes from the study of crowd dynamics, which straddles diverse fields such as modelling, engineering and physics, while also factoring in the psychology that determines how individuals behave in a crowd.

"It requires a combination of macroscopic, microscopic, activity-travel behaviour, and crowd behavioural/psychological studies, to get a comprehensive understanding of crowd dynamics and crowd risk-situations," said Ashish Verma, professor of civil engineering at the Indian Institute of Science (IISc), whose extensive research on the subject includes heading a 300-page report on the dynamics of the 2016 Kumbh Mela crowd in Ujjain. The report, prepared by Verma's transportation engineering lab at IISc, was published in 2019.

"Through scientific understanding of crowd dynamics, it is possible to predict crowd behaviour in normal and unexpected situations, and more importantly to control and contain their negative impact in terms of crowd risk situation," Verma told HT.

Researchers can observe a crowd at various scales. In some models, they borrow from fluid dynamics; just as molecules interact in a fluid medium, individuals too interact in various ways in a dense crowd, which is viewed as a continuous medium. Other models look at the density and velocity of an entire crowd and how these change in space and time, or how a queue in certain areas changes with time.

In all these models, variables that matter include the density of the crowd, the average speed, and the variance of speeds, and whether there are space constraints or insufficient exits, Helbing said.

"Besides this, researchers use video and data analyses and, to some extent, even experiments (within ethical bounds) to gain insights into the dynamics of crowds," he said.

Lessons learnt

In 2016, the Kumbh Mela Experiment by Verma and his colleagues studied the dynamics of the Ujjain crowd and identified potential risk factors. It found variable speeds and densities at various sections of the Mela procession, causing bottlenecks at dense locations. Other factors upsetting the equilibrium of the crowd included additional pressure from devotees (without permission) trying to sneak into the procession from the sides, and groups holding hands trying to percolate through the crowd.

"All these behaviours lead to situations of crowd risks and suitable measures have to be taken so as to avoid these crowd risks leading to crowd disasters," the report said.

It laid down a series of guidelines, such as restricting the crowd density to 6–7 persons per square metre, robust barricading and regulation of inflow to the ghat for the holy dip. While these have not been implemented yet, Verma said his group plans to seek permission for similar studies on the next mela in 2028 and other religious events in between.

In 2006, following the Haj stampede, the Saudi government consulted Helbing to analyse the crowds and find ways to prevent future disasters. An analysis of videos identified some risky behaviour: as the crowd for the ritual stoning in Mina thickened, its movement changed from steady progress to waves (stop-and-go) and then to turbulence with people being randomly jostled in all directions.

Following Helbing's recommendations, the old pillars to be stoned were replaced with larger ones, an additional access route was designed, and a mandatory schedule was introduced to ensure pilgrims would no longer meander at will.