Assessment of Head Injury Risks from Falling Objects: A Finite Element Analysis of Helmet Protection

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Summary

This study analysed the risk of head injuries, particularly concussions, caused by falling objects in workplace accidents. A case study is presented, focusing on a construction worker who sustained a head injury despite wearing a protective helmet. Finite element (FE) analysis was used to model the helmet-head system and evaluate impact forces and head accelerations. The tested helmet, composed of High-Density Polyethylene with a 6-point suspension system, was subjected to impacts from falling objects weighing 332g and 665g. Simulations performed at drop heights ranging from 5 to 25 meters indicated that objects weighing as little as 332g could induce severe concussions from a 10-meter fall. The results demonstrate that while helmets provide some protection, they absorb considerably less energy than the kinetic energy of falling objects. The analysis confirmed the worker's account that his injury resulted from a foreign object impacting his helmeted head.

Introduction

This study assessed whether a protective helmet mitigated severe injury when a falling object hit a worker's head. The case involved a 58-year-old male construction worker who was hit by a falling object, likely a brick or concrete fragment, while walking near a six-floor building under renovation. Despite wearing a helmet, he lost consciousness and fell. He sustained a concussion, cervical spine contusions, and abrasions on his hands and forearms. The employer attributed the fall to transient heart weakness rather than external impact. However, witnesses confirmed ongoing removal of loose concrete from balconies and inspection of iron reinforcements. The victim was found lying face down on his right cheek, 1.6 meters from the building. Nearby, two concrete fragments (332 g and 665 g) and a damaged helmet were discovered, with abrasions on its right rear side. No witnesses observed the moment of impact or fall, and the object's exact drop height remained unknown. The expert's task was to determine the object's required mass and height to cause the observed helmet damage, fall, concussion, and unconsciousness.

Methods

A FE model of the helmet-head system was developed to analyze the impact effects of a falling object on a helmeted head. The model included a geometrically accurate helmet shell with a six-point suspension system and a head-neck assembly. FE simulations were realised in Abaqus programme using simplified geometric representations with material properties sourced from manufacturers and literature. The head-neck model incorporated connector elements with predefined stiffness values. The impacting object was modeled as a 50×50×70 mm block with a density comparable to bricks or concrete. The simulations aimed to determine head acceleration, velocity, and cervical forces

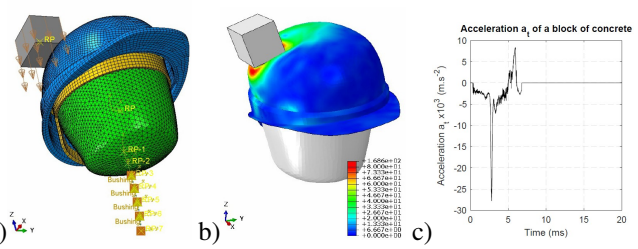

Figure 1: a) Demonstration of a numerical FE model of a head with helmet, cervical vertebrae and falling foreign body. b) Magnitude of the reduced stresses σ_{red} [MPa] on the helmet during the impact of a foreign body on the helmet. c) Graph of the vertical acceleration a_t the falling object.

resulting from the impact of a 332 g or 665 g object dropped from heights of 5 to 25 m. The initial velocities were derived from free-fall kinematics. The C7 vertebra was fully constrained, and explicit dynamic analysis was realised.

Results and Discussion

A 50% probability of concussion occurs when head acceleration exceeds 78 g. This limit was surpassed in all simulated cases, except for a 332 g object falling from 5 m. In contrast, a 665 g object falling from 25 m exceeded this limit by more than 3.5 times. Similarly, Nahum at al. [1] report a helmet safety threshold of 300 g, which was exceeded in all cases except for the 332 g object falling from 5 m. The Head Injury Criterion (HIC) is another key parameter in concussion risk assessment, with a critical threshold of 230 [2]. All simulations exceeded this limit, except for the 332 g object from 5 m.

Conclusions

The precise size of the object responsible for the victim's concussion could not be determined. Numerical FE simulations indicate that even a 332 g object falling from a height of 10 m or more has at least a 50% probability of causing a concussion. A 665 g object could generate sufficient acceleration from 5 m or higher to produce the same risk. Both scenarios are plausible in the case of an object striking the head of a helmeted victim. Photographic evidence from the police confirms that the helmet damage resulted from the impact of a foreign object, not from the victim or helmet striking the ground or kerb. The object likely fell from a nearby structure while the plaintiff was walking in its vicinity. The second balcony was estimated at 11–12 m. A 332 g object falling from this height could cause concussion and cervical spine contusion, while a 665 g object from the first balcony and above could induce severe head injury.

References

[1] Nahum A. et al. (2002). *Accidental Injury: Biomechanics and Prevention*; Springer.
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