CRATER FORMATION IN SOILS BY RAINDROP IMPACT

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ABSTRACT

The process of crater formation by the impact of water drops on soil, sand and various other target material was studied. Craters of various shapes and sizes were observed on different target materials or conditions, ranging from circumferential depression to completely hemispherical shape. Crater shape was dependent upon target material, its flow stress or shear strength and the presence and thickness of water on the surface. Between 5 and 22 per cent of impact energy was spent on cratering, but the relationship between crater volume and kinetic energy of a raindrop was curvilinear, indicating a lower efficiency of impact energy in removing target material as the energy increases. Impact impulse, on the other hand, showed a more linear relationship with crater volume, and the ratio of impulse over crater volume (I/V) remained constant for the entire range of drop sizes, impact velocities, and surface conditions used in this study. Surface shear strength, represented by the penetration depth of fall-cone penetrometer, appeared to be a key factor involved in this process. An equation was developed which related crater volume to cone penetration depth and impact impulse. Crater volume, which appeared to be a better indicator of the total amount of material dislodged by a raindrop than splash amount, can thus be predicted using this equation.

KEY WORDS: raindrop impact; rain erosion; impact erosion; cratering; impact cratering; cavity formation; splash erosion

INTRODUCTION

Single drop impact and photographic studies of the 1970s and 1980s revealed that rain erosion can be divided into three inter-related processes of impact, splash and cratering (Ghadiri and Payne, 1977, 1981). The impact and splash processes have since been studied by many researchers and are well understood (Ghadiri and Payne, 1986, 1988; Al-Durrah and Bradford, 1981, 1982; Nearing *et al.*, 1986, 1987; Nearing and Bradford, 1985, 1987; Sharma and Gupta, 1989). Cratering, or the process of cavity formation by a falling raindrop digging into the soil or other target materials, on the other hand, has not received much attention in soil erosion research. Its mechanism is not known, nor is its role and significance in the processes which lead to the removal and transport of soil material. Even in the field of alloys and metals, erosion under very high (supersonic) impact velocities of raindrops or water sprays where crater formation or target penetration is the main concern, the process is not fully understood (Adler, 1999). A few empirical equations have been developed for the supersonic impact of water drops onto a liquid surface (Engel, 1961, 1962, 1966), water drops onto a solid surface (Pitek & Hammitt, 1966; Rinehart, 1950; Van Valkenburg *et al.*, 1956; Adler, 1991), and solid spheres onto a solid surface (McKenzie *et al.*, 1959; Mihara, 1952; Summer and Charters, 1960), where crater volume has been equated with the energy or some other factors of the impacting drop or projectile. However, the applicability of such equations to cratering in low strength granulated material such as soil by the low velocity impact of free-falling raindrops has not been tested.

Most of the empirical equations developed for supersonic collision of liquid drops with solids relate crater depth, diameter or volume to an exponent of impact velocity. None of these equations contributed significantly to a fundamental understanding of the flow of material under impact which leads to crater formation (Cook, 1959; Engel, 1961; Pitek and Hammitt, 1966). Target strength, as a parameter in these empirical equations, appears to play a secondary role to sound velocity, which is a function of elastic properties of targets. It is not clear why elastic properties affect a process which is dominated by plastic flow.

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The only study of crater formation by the impact of free-falling water drops at near-terminal velocities was carried out some 40 years ago by Engel (1961). This study resulted in the development of the following empirical equation:

$$D = KR(\rho V^{2})^{\frac{1}{3}}$$

in which D is the maximum cavity depth, K is a constant, and V, R and ρ are the velocity, radius and density of the falling drop respectively.

The only study in which crater formation in granulated material by free-falling water drops has been briefly mentioned is the one carried out by Mihara (1952). He found a linear relationship between crater volume and impact velocities higher than 1 m s^{-1}.

This paper reports on a comprehensive investigation into crater formation in soil, sand, pastes of various simple chemicals and water targets by free-falling water drops of different sizes, heights of fall and fall velocities. This study offers a new approach to rain erosion research in which the behaviour of the raindrop and soil surface as the two colliding bodies is considered.

METHODS

Photography

Crater and splash corona formation by the impact of water drops on water targets of various depths, and their eventual collapse was photographed using a high-speed cine photographic technique. The camera used was a Hitachi High Speed Motion Analysis Camera (HIMAC) which is a rotating prism type, having speeds of up to 10 000 pictures per second. The actual speed of the frames on which impact was caught was measured from the timing marks made on the film by a timing device. Filming was carried out through the transparent walls of the container of target water with the camera lens parallel to the water surface. A light-sensitive diode was used as an automatic triggering device, which was coupled with an event synchronizer to delay the actual shooting of the event at a predetermined elapse time following the release of the water drops from the top of a 9 m tall tower. Back-lighting with a 600 watt bulb focused onto the camera lens was used for target illumination.

The films were projected onto large graph papers, stopped on each frame, and the outlines of crater and corona were drawn on the paper. The elapsed time since impact was also determined and recorded on the drawing of each still frame (Figure 1). These drawings were then used to determine the depth and diameter of the crater at various time intervals after impact. The formation, growth and eventual collapse of the splash corona on the rims of the crater were also recorded and measured on these drawings or directly from the projected still frames. The sequences showing the entire processes of crater and corona formation and collapse were prepared by printing one in every 10 to 50 frames after impact and arranging them as shown in Figure 2.

Water drop formation

A full range of glass droppers was made, which were capable of producing drops of 14 to 158 mg (equivalent spherical diameter of 3 to 6·7 mm). The relationship between the diameter of glass jets and that of the drop they form (Laws, 1941) was used for making the droppers capable of producing drops of the required diameters. The drops were released from different heights, ranging from 1 m to 8 m height of fall, at 1 m increments. Drop weight was determined by collecting and weighing 100 drops in a pre-weighed beaker.

Target preparation

Duplicate samples of soil, sand and chemical paste were prepared with a wide range of water contents and used simultaneously, one as a target for water-drop impact and the other for fall-cone penetration. Non-liquid targets were prepared in Petri dishes of known weight and following the landing of a single water drop on the targets splash loss was determined by reweighing the sample. The depth and diameter of the crater formed by water-drop impact were measured immediately following the impacts as discussed below.

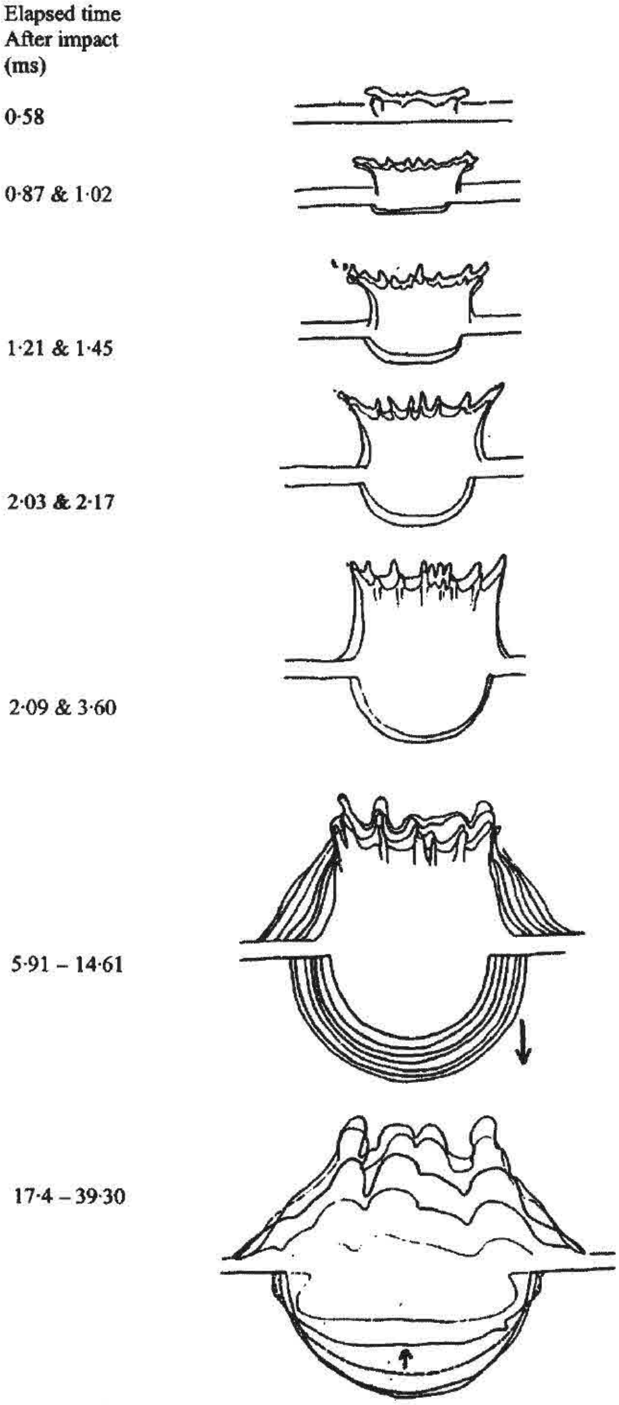

Figure 1. Tracing and measurement of the growth and collapse of craters formed by water drop impacts on water targets

Crater cast penetration

A collection of crater casts was prepared by impacting water drops of various sizes and velocities on different targets and then filling them with a slurry of plaster of Paris. The casts were removed after setting, and were washed, dried and dipped into resin, then their dimensions measured. They were pushed onto the targets on a

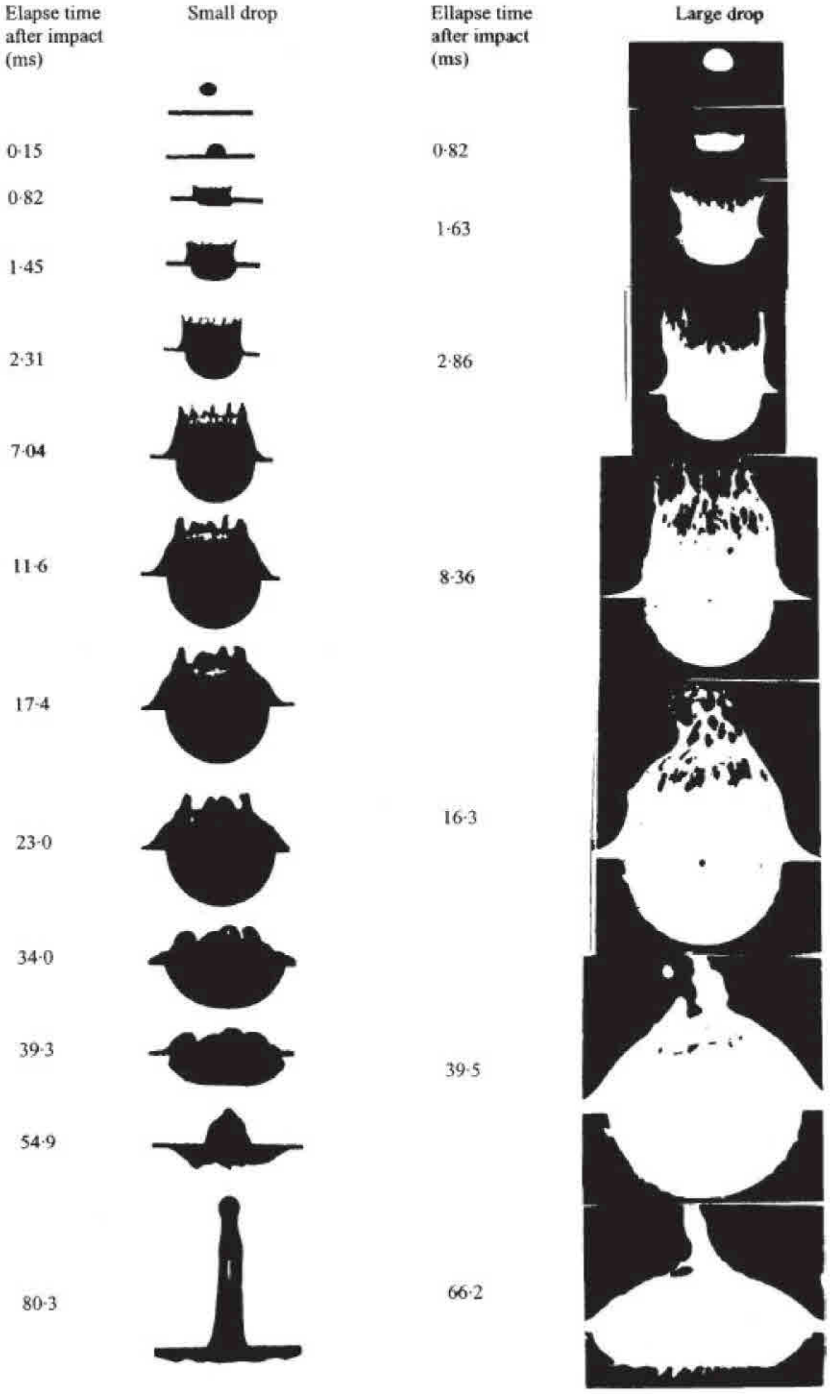

Figure 2. Photographic sequences of crater and corona formation, growth and collapse following the impact of a small drop (left) and a large drop (right) on water targets