EWRI/ASCE 39-03

ASCE STANDARD

American Society of Civil Engineers

Standard Practice for the Design and Operation of Hail Suppression Projects

This document uses both Système International (SI) units and customary units.

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Abstract
This document describes a process through which hail suppression operations should be designed, organized, and conducted. The information contained herein is intended to be helpful to those persons wishing to implement operational hail suppression activities, and provides information on the design, conduct, and evaluation of such efforts. While not a technical meteorological monograph on the subject, it is intended to provide the best scientific information currently available on the subject to optimize the likelihood of success.

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STANDARDS

In April 1980, the Board of Direction approved ASCE Rules for Standards Committees to govern the writing and maintenance of standards developed by the Society. All such standards are developed by a consensus standards process managed by the Management Group F (MGF), Codes and Standards. The consensus process includes balloting by the balanced standards committee made up of Society members and nonmembers, balloting by the membership of ASCE as a whole, and balloting by the public. All standards are updated or reaffirmed by the same process at intervals not exceeding 5 years.

The following Standards have been issued:

ANSI/ASCE 1-82 N-725 Guideline for Design and Analysis of Nuclear Safety Related Earth Structures
ANSI/ASCE 2-91 Measurement of Oxygen Transfer in Clean Water
ANSI/ASCE 3-91 Standard for the Structural Design of Composite Slabs and ANSI/ASCE 9-91 Standard Practice for the Construction and Inspection of Composite Slabs
ASCE 4-98 Seismic Analysis of Safety-Related Nuclear Structures
Building Code Requirements for Masonry Structures (ACI 530-02/ASCE 5-02/TMS 402-02) and Specifications for Masonry Structures (ACI 530.1-02/ASCE 6-02/TMS 602-02)
SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures
ANSI/ASCE 8-90 Standard Specification for the Design of Cold-Formed Stainless Steel Structural Members
ANSI/ASCE 9-91 listed with ASCE 3-91
ASCE 10-97 Design of Latticed Steel Transmission Structures
SEI/ASCE 11-99 Guideline for Structural Condition Assessment of Existing Buildings
ANSI/ASCE 12-91 Guideline for the Design of Urban Subsurface Drainage
ASCE 13-93 Standard Guidelines for Installation of Urban Subsurface Drainage
ASCE 14-93 Standard Guidelines for Operation and Maintenance of Urban Subsurface Drainage
ASCE 15-98 Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations (SIDD)
ASCE 16-95 Standard for Load and Resistance Factor Design (LRFD) of Engineered Wood Construction
ASCE 17-96 Air-Supported Structures
ASCE 18-96 Standard Guidelines for In-Process Oxygen Transfer Testing
ASCE 19-96 Structural Applications of Steel Cables for Buildings
ASCE 20-96 Standard Guidelines for the Design and Installation of Pile Foundations
ASCE 21-96 Automated People Mover Standards—Part 1
ASCE 21-98 Automated People Mover Standards—Part 2
ASCE 21-00 Automated People Mover Standards—Part 3
SEI/ASCE 23-97 Specification for Structural Steel Beams with Web Openings
SEI/ASCE 24-98 Flood Resistant Design and Construction
ASCE 25-97 Earthquake-Actuated Automatic Gas Shut-Off Devices
ASCE 26-97 Standard Practice for Design of Buried Precast Concrete Box Sections
ASCE 27-00 Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction
ASCE 28-00 Standard Practice for Direct Design of Precast Concrete Box Sections for Jacking in Trenchless Construction
SEI/ASCE/SFPE 29-99 Standard Calculation Methods for Structural Fire Protection
SEI/ASCE 30-00 Guideline for Condition Assessment of the Building Envelope
SEI/ASCE 32-01 Design and Construction of Frost-Protected Shallow Foundations
EWRI/ASCE 33-01 Comprehensive Transboundary International Water Quality Management Agreement
EWRI/ASCE 34-01 Standard Guidelines for Artificial Recharge of Ground Water
EWRI/ASCE 35-01 Guidelines for Quality Assurance of Installed Fine-Pore Aeration Equipment
CI/ASCE 36-01 Standard Construction Guidelines for Microtunneling
SEI/ASCE 37-02 Design Loads on Structures During Construction
CI/ASCE 38-02 Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data
EWRI/ASCE 39-03 Standard Practice for the Design and Operation of Hail Suppression Projects

FOREWORD

In April 1995, the Board of Direction approved the revision to the ASCE Rules for Standards Committees to govern the writing and maintenance of standards developed for the Society. All such standards are developed by a consensus standards process managed by the ASCE Codes and Standards Activities Committee (CSAC). The consensus process includes balloting by a balanced ASCE Environmental and Water Resources Institute (EWRI), Atmospheric Water Management (AWM) Standards Committee (SC), made up of Society members and nonmembers, balloting by the membership of ASCE as a whole, and balloting by the public. All standards are updated or reaffirmed by the same process at intervals not exceeding five years.

The provisions of this document have been written in permissive language and, as such, offer to the user a series of options or instructions but do not prescribe a specific course of action. Significant judgement has been left to the user of this document.

This document describes a process through which hail suppression operations should be designed, organized, and conducted. The information contained herein is intended to be helpful to those persons wishing to implement operational hail suppression activities, and provides information on the design, conduct, and evaluation of such efforts. While not a technical meteorological monograph on the subject, it is intended to provide the best scientific information currently available on the subject to optimize the likelihood of success. ASCE Manual No. 81, *Guidelines for Cloud Seeding to Augment Precipitation* (Kahan et al. 1995), is referenced in many sections of this guideline.

This standard has been prepared in accordance with the CSAC Style Manual, 4 September 1998 revision, with recognized engineering principles, and should not be used without the user's competent knowledge for a given application. The International System of Units (SI units) is used throughout, with English equivalents also provided. Exceptions are the use of the Celsius (°C) temperature scale and, where appropriate, centimeters (cm) in lieu of meters (m). Section 8 provides all conversion factors used herein. Italics denote special emphasis.

The publication of this standard by ASCE is not intended as warrant that the information contained therein is suitable for any general or specific use, and the Society takes no position respecting the validity of patent rights. The user is advised that the determination of patent rights or risk of infringement is entirely their own responsibility.

Many contributed materially to this document by their comments, review, illustrations, and photographs. The primary authors of this document were the ASCE EWRI AWM SC Hail Suppression Subcommittee members: Bruce A. Boe (chair), Arnett S. Dennis, Andrew G. Detwiler, Thomas J. Henderson, Terrence W. Krauss, Griffith M. Morgan, James H. Renick, and José Luís Sánchez. Others who contributed materially include Magomet T. Abshaev, Thomas P. DeFelice, Richard D. Farley, William G. Finnegan, Don A. Griffith, Conrad G. Keyes, Jr., Nancy C. Knight, Fred J. Kopp, Harold D. Orville, Petio Simeonov, Paul L. Smith, and Richard H. Stone.

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1.0 THE HAIL PROBLEM

Unlike other forms of precipitation, hail comes in bursts of short duration, falls over isolated and unpredictable locations, and usually occupies only a small percentage of the total area covered by precipitation during any given storm. Nonetheless, the sudden, instantly visible destruction caused by hail can have devastating financial and emotional impacts. It is not surprising, therefore, that people in many places have attempted to avert hail damage to their crops and other property.

1.1 HISTORICAL PERSPECTIVE

People in ancient times employed magic, including incantations, shouted and shook their fists, hurled lances, and shot arrows skyward in attempts to rout oncoming hailstorms. In Europe in the Middle Ages, Christians resorted to prayer and the ringing of church bells. It is not clear whether the ringing of the bells was expected to produce a physical effect or was viewed simply as an invocation of God's protection against impending disaster.

The introduction of gunpowder led to another approach to hail suppression. It was thought by some persons that explosions could somehow disrupt the hail formation process, and so the hail cannon was developed. Hundreds of cannon were in operation, mainly in European countries near the Alps, in the years just before World War I, and their use continued on a smaller scale after that conflict ended. A number of theories were advanced to justify the use of hail cannons. For example, shock waves were postulated either to disrupt the updraft required for hail formation, to soften the falling hailstones, or to induce the freezing of supercooled water droplets essential for hail development. Whether or how these effects might be adequately achieved by cannons was never resolved.

Small rockets containing explosive charges and developed in Italy were an outgrowth of the hail cannon technology. As early as 1937, these devices were being fired at storms from the ground. France, Switzerland, Kenya, and South Africa followed with similar trials, some of which lasted until 1960 or later. Some users of the devices argued that the shock waves they produced could soften or even shatter hailstones, especially if the hailstones contained pockets of liquid water.

Modern hail suppression technology is based on discoveries at the General Electric Research Laboratories in the late 1940s (Schaefer 1946, Vonnegut 1947) regarding the ice nucleating properties of dry ice and silver iodide. As it was well known that hailstone growth depended upon a supply of supercooled water in the hail-producing clouds, it was reasoned that artificial freezing of that supercooled water would suppress the formation and growth of hail. Commercial hail suppression operations involving the release of silver iodide from ground-based generators and from aircraft became quite common in the United States during the 1950s. Experimental programs were undertaken in many other countries as well. A few such programs are mentioned below. The most extensive projects were undertaken by scientists and engineers in the U.S.S.R., who pioneered new techniques for delivery of silver iodide or other seeding agents to target clouds. By the 1960s, their arsenal of anti-hail weapons included artillery shells and quite sophisticated rockets. On the basis of comparisons of crop damage in protected areas and in neighboring unprotected areas, substantial hail suppression effects were claimed (Atlas 1965, Battan 1965).

An extensive network of ground-based silver iodide generators has been used to suppress hail in southwestern France since 1951. Although targeting is less certain than with rockets or aircraft delivery systems, the program's operators consider it successful. For the period from 1965 through 1982, they report a decrease in hail damage on the order of 40% (Dessens 1986), and more recently, for the years 1988–1995, a decrease of 42% (Dessens 1998).

One of the most extensive hail suppression research projects began in Alberta, Canada, in 1956. In one of the regions of greatest hail frequency in the world, the hail insurance premiums approached one-quarter of the crop value. Airborne seeding served as the major method of dispensing the silver iodide nuclei. Although a research project was conducted for more than 30 years, with 14 years of cloud seeding, the participating scientists were unable to reach a conclusion about the effectiveness of hail suppression. The Alberta research effort is currently inactive, but an operational hail suppression project was launched in 1996, funded entirely by the property and casualty insurance companies (Krauss and Renick 1997).

In Kenya, Africa, a 7-yr operational hail suppression program was conducted over tea estates where the hail frequency averages nearly 200 days per year. Pyrotechnics containing silver iodide were burned on