Fog Mitigation Update: Fog Mitigation Measures as Applied to Highway Bridge Structures

CORY B. POTASH AND JAMES R. BROWN

In response to a court action, a plan was developed to mitigate potentially hazardous effects of fog on a proposed highway bridge. The proposed site is subject to naturally occurring fog in addition to fog consisting of large quantities of water vapor emitted by a paper mill. A study was conducted to evaluate available mitigation measures. The measures evaluated include dispersion systems, guidance systems, design alternatives, transportation management, and incident detection. The purpose of this paper is to present the conclusions of the study. On the basis of the study results, a fog mitigation plan was recommended. The plan consists primarily of guidance and surveillance measures. The major components of the recommended plan include fixed message signs, raised reflective pavement markers, lighted pavement markers, highway surveillance, and variable message signs. The recommended plan was accepted by the governing agency and will be implemented. In addition, other considerations, which are presented in this paper, will be explored while the proposed bridge is under construction.

The Recommended Transportation Plan for the Charleston, South Carolina area, completed in 1968 and updated in 1975 and 1976, includes the proposed construction of the Mark Clark Expressway. The western segment of the expressway was approved for funding by FHWA in 1970, and a large portion of this segment has been constructed.

The eastern segment of the expressway would include a bridge spanning the Cooper River near a paper mill owned and operated by Westvaco, Inc. The mill emits over 6 million gallons of water vapor per day into the atmosphere. The eastern segment of the Mark Clark Expressway would be partially funded by federal aid highway funds and, as such, must meet all U.S. Department of Transportation (DOT), FHWA, and National Environmental Policy Act (NEPA) requirements. In conformance with these requirements, the South Carolina Department of Highways and Public Transportation (SCDHPT) completed a Final Environmental Impact Statement (FEIS) for the project, which was approved by FHWA. Subsequent to completion of the FEIS, Westvaco filed a complaint in the U.S. District Court for the District of South Carolina Charleston Division, alleging, among other things, violation of NEPA because SCDHPT and FHWA failed to address in the FEIS the threat to highway safety presented by fog.

C. B. Potash, 250 West 104th St., No. 21, New York, N.Y. 10025. J. R. Brown, Parsons Brinckerhoff Quade & Douglas, Inc., 1 Penn Plaza, New York, N.Y. 10119.

The complaint asked that the SCDHPT and FHWA be enjoined from engaging in any further activities directed toward building the bridge until they had complied with the NEPA. In conjunction with this action, Westvaco had prepared a series of studies evaluating the potential impact of naturally occurring fog and fogging caused by the large quantities of steam released from the Westvaco paper mill (mill-induced fog) on traffic and safety conditions at the proposed location of the Cooper River Bridge. The company also prepared studies evaluating alternative bridge locations and the feasibility of constructing a tunnel, rather than the proposed bridge.

SCDHPT reevaluated the proposed bridge in consideration of Westvaco's concern over the potential fog problem. As part of the reevaluation, SCDHPT prepared an independent evaluation of the potential for fog occurrences on the proposed Cooper River crossing. Subsequently, the SCDHPT issued an environmental assessment, based on their reevaluation, which concluded that fog would have no significant impact on the safety of motorists using the Cooper River Bridge at its proposed location. FHWA concurred with the conclusions of the environmental assessment and decided that it was unnecessary to supplement the FEIS.

After consideration of the additional studies completed by Westvaco and SCDHPT, and additional expert testimony, the court ruled not to enjoin the project but required SCDHPT and FHWA to file a Supplemental Environmental Impact Statement (SEIS) to consider the impact of fog on the proposed bridge and to prescribe the specific actions to be taken to mitigate any potential hazards due to fog.

In conformance with the court's order, the SCDHPT requested Parsons Brinckerhoff Quade & Douglas, Inc. (PBQD) to evaluate and propose measures to mitigate the potential fog hazards on the proposed Cooper River Bridge. In conducting the study, it was understood that there is no reasonable measure to completely eliminate the potential for accidents on the proposed Cooper River Bridge, with or without fog. The exploration of available measures sought to identify measures that would reduce the probability and severity of accidents occurring on the proposed Cooper River Bridge to levels approaching or equal to those without fog, although it was recognized that such levels may not be achievable. Recommended measures, however, are considered to be the most effective generally available measures to improve safety conditions on the proposed Cooper River Bridge under fog conditions. It is believed that the recommended measures, when applied as a comprehensive mitigation system, would significantly reduce the frequency and severity of accidents on the proposed structure during fog.

NATURE AND EXTENT OF THE FOGGING PROBLEM

Fog decreases visibility and makes driving more difficult and dangerous. Traffic studies indicate that although driving speed is reduced in fog, the probability of overdriving the safe stopping distance is greatly increased. Accident statistics indicate that there is a greater likelihood of multivehicle accidents and fatal accidents in fog. Dangers due to fog are accentuated on Interstate highways, as compared to arterial roadways, because of the increased speeds and greater traffic levels found on Interstates.

Mill-induced and natural fog occurs in the Charleston area throughout the year, particularly during the nominal "fog season," November through March. On a daily basis, natural fog is more likely to be present during the cooler nighttime and early morning hours, which are characterized by relatively stable atmospheric conditions, than during the warmer daytime and early evening hours, when there is greater vertical mixing of air in the atmosphere. The paper mill emits over 6 million gallons of water vapor per day into the atmosphere from some 50 different sources.

By using computerized analytical dispersion models, it was predicted that the combination of natural and mill-induced fog would result in a reduction in visibility to less than 660 ft perhaps 12–15 times per year. That fog is more dense in the vicinity of the Westvaco paper mill was confirmed by the testimony of two Charleston harbor pilots, with over 40 years of combined experience in traversing the branch of the Cooper River near the mill and bridge site. They stated that they had personally experienced denser fog near the paper mill about 12–15 times per year (*1*). Although visibility within either type of fog can be significantly reduced, observations of the water vapor plumes emitted from the paper mill indicate that depending on wind speed and direction and the vertical temperature profile of the atmosphere, mill-induced fog can appear and disappear very rapidly at a particular location as the wind changes speed and direction.

Measures are required to mitigate the potential impact of fogging conditions on the 30,000 vehicles per day that are expected to use the Cooper River Bridge by the year 2000 and, especially, to improve safety conditions for the approximately 1,800 vehicles per hour that will traverse the bridge in the relatively fog-prone early morning peak traffic hour, from 7:00 a.m. to 8:00 a.m. Because of the mild climate in the Charleston area, ice formation was not considered to be a significant problem and therefore was not a subject of this mitigation effort.

RECOMMENDED MITIGATION MEASURES

Available mitigation measures were identified and evaluated on the basis of effectiveness, availability and reliability, cost, and general practicability. Measures evaluated include dispersion systems, design alternatives, guidance systems, and transportation management alternatives. None of the dispersion methods were determined to be effective in a highway bridge application and therefore are not included in the recommended fog mitigation plan. Similarly, bridge design alternatives would have required both significant project delays and potential redesign of the bridge, and therefore these alternatives were not considered to be feasible mitigation measures.

The principal criteria used in the selection of mitigation measures was whether the proposed method has been shown to increase safety in similar highway applications during fog events. The proven ability to reduce impacts, rather than the ability of a measure to completely eliminate fog or its impacts, was the realistic goal of this study because there are no methods that can eliminate the chance of an accident occurring during fog. The goal of the selected fog mitigation plan was to reduce the probability and severity of accidents in fog to levels approaching or equal to those without fog.

The recommended mitigation plan does not include measures to reduce the frequency, duration, and intensity of the fogging events, such as applying controls to limit vapor released at the Westvaco paper mill. Instead, the measures identified were selected to provide effective assistance to drivers encountering intense fog conditions on the Cooper River Bridge.

The major elements of the recommended fog mitigation plan included the following:

- *Fixed permanent single message signs indicating that the bridge is prone to fog.*
- *Raised reflective pavement markers to delineate roadway edgelines and lane delineation lines.* National guidelines for the placement and spacing of raised reflective pavement markers have not been formally adopted. The suggested arrangement of raised reflective pavement markers shown in the FHWA *Traffic Control Devices Handbook* (2) indicates that raised reflective pavement markers can be spaced between 20 ft and 40 ft apart when used to supplement pavement striping. During wet or fog conditions, pavement is not always visible, and this loss of visibility occurs when pavement striping is most needed to delineate lanes. Therefore the spacing of raised reflective pavement markers (yellow on the left, white on the right) should be spaced on 20-ft (minimum standard) to 10-ft (desirable standard) centers. The raised reflective pavement markers indicating the lane delineation line should be arranged to simulate standard broken line marking (10-ft marking segments interspersed with 30-ft gaps). Three white raised reflective pavement markers should be installed at the beginning, middle, and end of the 10-ft marking segments. Transverse marking of the shoulder area is recommended to reinforce delineation of the right edge of the travelway and to define the shoulder refuge area. The shoulder marking should be spaced on 40-ft intervals with four to six white raised reflective pavement markers.
- *Lighted pavement markers on ~200-ft centers along roadway edgelines to provide long-range delineation of the roadway beyond the reach of vehicle head lamps.* Lighted pavement markers are recommended to provide daytime guidance during fog conditions and to provide long-range guidance when fog reduces vehicle headlight range so that only nearby raised reflective pavement markers are illuminated. Standard high-intensity unidirectional lighted pavement marker units have been used in roadway application. The unit is 12 in. in diameter

and is available with 3½-in. or 9-in. base, which can be inserted into the bridge deck and the pavement of the approach roadway.

A driver normally views the roadway up to 1,000 ft in front of the vehicle. As driving and visibility conditions worsen, the driver's visibility range will be reduced to 400 ft or less. At a minimum, a driver should be able to see two sets of lighted pavement markers to maintain proper roadway orientation. Placing lighted markers ~200 ft apart will provide the minimum number of markers required to maintain proper roadway orientation (2). A review of the engneering plans for the proposed bridge indicates that a spacing of ~200 ft can be maintained throughout the length of the bridge, including the 1,600-ft vertical curve main spans of the bridge.

- *Increased highway surveillance by highway troopers and the installation of a closed circuit television system to provide timely detection of fog conditions.* Television cameras permanently mounted on the bridge truss would be directed toward a series of targets (e.g., simulations of tail lights) placed at predetermined incremental distances along the portion of the bridge prone to mill-induced fog. The signals from the cameras would be transmitted to dedicated television monitors at the local Highway Trooper District office. The number of targets visible on the monitor would provide an estimate of the degree of visibility on the bridge directly proportional to site distance. State highway troopers will provide increased on-site surveillance during the nominal November through March fog period and, more particularly, during periods when meteorological conditions are expected to cause fumigation of the proposed bridge by mill-generated vapor. Such a determination could be made by a qualified, certified meteorologist experienced in weather forcasting.

On the basis of the results of increased surveillance by state highway troopers or estimates of sight distance determined from the dedicated television monitors, additional response procedures would be implemented. These measured include activation of lighted pavement markers, activation of illuminated variable message display units to provide advance warning and instructions to drivers concerning upcoming fog conditions, and the implementation of transportation management measures. The specific techniques to be applied would depend on the severity of the observed fog conditions. Such techniques would be applied on the basis of a predetermined response agenda.

- *Overhead sign bridges with internally illuminated variable message display units to provide specific fog incident information to the driver.* The overhead sign bridges should be located outside of each end of the fog-prone area to warn motorists of existing or potentially hazardous conditions. The location of these bridges should be such that traffic could divert to alternative roadways. The location of these bridges in relation to the roadway alignment should be tested with procedures recommended in Section 2C-3, Placement of Warning Signs, of the *Manual on Uniform Traffic Control Devices* (3). These variable message warning signs would be placed on the approaches to the bridge to provide advance warning and instruction to drivers about potential fog conditions on the bridge, specifying lower speed limits during fog conditions and providing motorists with additional directives and information on driving conditions and required actions.

The measures recommended in this study make up a system of interrelated guidance and transportation techniques that function both independently and in association to improve safety conditions on the Cooper River Bridge during fog. The basic level of protection in the system consists of two permanent passive measures: permanent single-message warning signs and raised reflective pavement markers. These are the simplest and least specialized components of the system and would function regardless of the state of any other system component.

The second area of protection within the system is surveillance. Both manned (highway trooper) and remote (television monitor) elements are recommended for detection of hazardous conditions and accidents on the bridge. This redundancy is intended to increase the reliability of this portion of the fog protection system, which is used to activate other key system components.

The third level of the system is the enhanced guidance component. This consists of the lighted pavement markers, which will be used to supplement the raised reflective pavement markers during fog events.

The fourth element of the system, the variable message signs, would provide motorists with warnings and information relevant to the specific fog event. The messages given by such a system could include a broad range of information, including advanced warning of fog conditions, speed regulations, required diversions, and information on other required traffic management controls. Such traffic management controls could include total diversion of traffic from the bridge.

The interrelationship and redundancy of the different elements of the system give the system a built-in resiliency. Failure of individual components of the system (because of electric power interruption, for instance) would still leave basic components of the system intact (raised reflective markers, fixed panel signs, and increased surveillance by highway troopers). An emergency diversion plan would remain an option under these circumstances, should conditions warrant it.

OTHER CONSIDERATIONS

The 4-year bridge construction period provides an opportunity for SCDHPT to refine its selected mitigation measures and study the fog situation further. Given the time available, the following measures were proposed for consideration by SCDHPT.

Monitoring

While the bridge is under construction, there is an opportunity to collect additional data along the actual elevated roadway segment on the frequency, duration, and extent of fogging. Suitable meteorological and automatic fog-detecting devices would be used. This information can be used to better define the geographic and temporal extent of the fogging problem, allowing for better definition and specification of the mitigation program. Monitoring of fog conditions during the construction phase could be used to identify the specific locations where proposed mitigation measures are to be applied, including the location of closed circuit television cameras, lighted pavement markers, and variable message signs.

Lighting Study

Fixed area lighting is not currently planned for the Cooper River Bridge, although the bridge design would not prohibit the implementation of such lighting. A detailed study of lighting on the bridge and approach sections of the highway may ultimately yield a cost-effective lighting system for the bridge segment under fog conditions. There are myriad lighting systems and system design variations. Recommendations as to the most appropriate lighting plan cannot be provided without careful and systematic study of various lighting programs available for the bridge. Such an evaluation is beyond the scope of this study but could be initiated during the 4-year bridge construction period to identify an effective system for use during fog conditions.

Fog Mitigation Update

The identification of measures to safeguard motorists during fog conditions is an ongoing process of research and development. A continuing program of literature review and research on fog mitigation would allow SCDHPT to remain current on fog-related safety programs for roadways. A periodic survey of the literature and communication with other state highway officials may identify additional measures to minimize the effects of fog on safety conditions.

Advanced Detection Techniques

The use of automatic fog detectors (e.g., visiometers and backscatter equipment), high-resolution closed circuit television cameras, or other electronic devices currently under development could potentially prove to be an effective complement to the proposed mitigation measures. To be of value, such equipment must be reliable and proven in similar applications. Further detailed study of these devices could potentially identify reliable and proven equipment that could be used to augment the proposed mitigation measures, particularly in the areas of system activation and incident detection.

Response Agenda and Protocol

The individual measures to mitigate the impact of fog on safety identified in this study must be applied in a systematic, predetermined, and coordinated fog response system. Elements of such a system include identification of the specific responsibilities, protocols, and agenda for activating and implementing the various mitigation measures, as well as for informing the public as appropriate. This detailed response agenda and protocol must be documented, and responsible individuals must be trained in the various elements of the mitigation system.

REFERENCES

1. Westvaco Corporation v. the South Carolina Department of Highways and Public Transportation and the FHWA. CA 2: 85-0825-2, Charleston, S.C., 1986.
2. *Traffic Control Devices Handbook: An Operating Guide.* FHWA, U.S. Department of Transportation, 1983.
3. *Manual on Uniform Traffic Control Devices for Streets and Highways.* FHWA, U.S. Department of Transportation, 1978.

Publication of this paper sponsored by Committee on Visibility.