P1.6 USE OF OKLAHOMA MESONET AND NATIONAL WEATHER SERVICE DATA IN THE DEVELOPMENT OF CONTROL STRATEGIES FOR WINTER-TIME BRIDGE HEATING

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1. INTRODUCTION

Wintertime maintenance of highways has been a crucial task for transportation authorities in North America and Europe. Development of new technologies and improved weather forecasting procedures to reduce icy conditions on roadways and bridges has been a subject of research since the early sixties (Highway Research Board 1964; Henderson 1963). Technology related to the heating of bridge decks and overpasses to combat preferential icing during freezing and sub-freezing conditions has drawn the attention of transportation authorities in the US since the seventies (Ferrara and Yenetchi 1976; Lee et al. 1986; Anonymous 1998). The Geothermal Smart Bridge (GSB) project, which is currently under development at Oklahoma State University (OSU) is aimed at developing heating systems for bridge decks using ground source heat pump technology. The overall mission of the GSB project is to "research, design, and demonstrate technically feasible, economically acceptable, and environmentally compatible Smart Bridge Systems to enhance the nation's highway system safety and to reduce its life cycle cost".

The four major components of the bridge heating system are the ground loop heat exchanger, heat pump, bridge deck, and control system. This paper focuses on the first-generation control system that has been designed using computer modeling with weather data as the input. The basic premise of the first-generation control system module (CSM) relies on a rule-based system guided by the weather data available at nearby stations. However, on-site pavement/bridge-deck sensors can also be used to supplement the weather information. The control strategies for the ground source heat pumping, which are developed with input from real-time and near real-time weather information, are discussed in more detail in section 3 of this paper.

2. WEATHER DATA AND FORECAST PRODUCTS

2.1 *Oklahoma Mesonet Data*

The Oklahoma Mesonetwork (Mesonet), which was developed through a partnership between the University of Oklahoma (OU) and OSU, is a network of 114 automated weather stations distributed around the State of Oklahoma at an average distance of 32 km between stations (Elliott et al. 1994; Brock et al. 1995; Shafer et al. 2000). At each station, thirteen atmospheric and subsurface variables are measured and 5-min data summaries are relayed every 15-min to a central processing site in Norman, Oklahoma. The data from each remote station are broadcast over radio waves to a nearby sheriff, police or highway patrol station. The data then enter the Oklahoma Law Enforcement Telecommunications System (OLETS) and are sent through the main OLETS office in Oklahoma City to the Oklahoma Climatological Survey (OCS) housed at the OU campus in Norman.

Mesonet data have been found to be of high quality and useful for a variety of research applications (e.g., meteorology, hydrology, agriculture, etc.). Road Weather Information Systems (RWIS) are receiving considerable attention nationally, but a comprehensive system of this type has not yet been implemented in Oklahoma. The high space and time resolution of

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Mesonet data are making it possible for transportation authorities to better monitor weather conditions affecting Oklahoma's highways. Furthermore, Mesonet data have aided greatly in responses to wildfires, chemical spills, and other incidents that can affect surface transportation.

2.2 *National Weather Service Data*

The National Weather Service (NWS) operates 14 automated weather stations within the state of Oklahoma. These stations monitor a myriad of surface and atmospheric variables at 1-hr intervals. Among all the measured variables, temperature (both dry bulb and dew point), wind (speed, direction, gust), and precipitation (type and intensity) are relatively important ones for the CSM. In addition to continuous monitoring of weather variables, the NWS provides a variety of forecast products to integrate with the observed measurements. Some of the forecast and analytical products that are of interest for the GSB project are Revised Digital Forecast (RDF), Rapid Update Cycle (RUC), and NEXRAD (Next Generation Radar) WSR-88D (Weather Surveillance Radar 1988-Doppler) precipitation maps. The temporal resolution of these products varies from 1 to 12 hours. OCS makes these forecast and analytical products available to the GSB project through a cooperative arrangement.

The RDF data are human-edited forecasts that are derived from model outputs and the NWS forecaster's experience. This product is primarily developed for the general public and is available for a forecast interval of 3 and 12 hours at a county or city level depending on the variables of interest.

The RUC is available for 0-6 hour forecast windows and is considered to be one of the best forecast products of the NWS. The RUC has been anticipated to be of high value to the GSB project, since it provides a short-term forecast, has relatively high spatial resolution (RUC-1 at 60 km and RUC-2 at 40 km) and is derived from a numerical forecast model that is initialized using an analysis system.

The Doppler radar data (WSR-88D) has also been considered to be a high-value product for this project because it provides high spatial and temporal resolution on precipitation intensity and movement.

3. SMART BRIDGE CONTROL SYSTEM MODULE

The basic function of the control system in the geothermally heated bridge is to meet the conflicting demands of ice-free bridge conditions with minimum capital and operating costs. It provides the ability to engage and disengage the heat pump without manual intervention and makes use of weather data to predict effective heat-pump operating parameters. Detailed discussion of the control system is beyond the scope of this paper and can be found elsewhere (Callihan 2000). The overall conceptual diagram for the CSM is presented in Fig.1 below.

The control system consists of two components, 1) feedforward, and 2) feedback. The feedforward component predicts the arrival time of freezing weather at the bridge site and signals the need to turn on the bridge heating. The feedback component maintains the average bridge temperature at a predetermined setpoint by adjusting the heat flux to compensate for fluctuations caused by the ambient weather conditions and the heat pump.

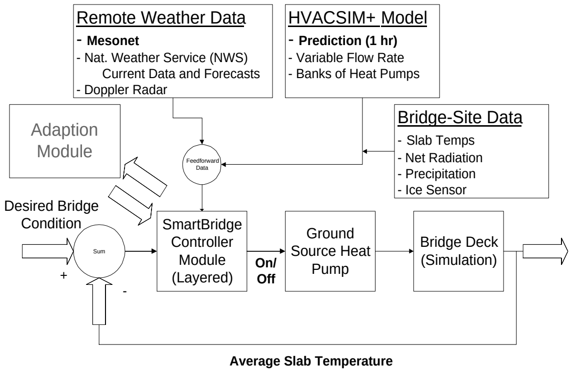

Fig. 1 Conceptual diagram of control system

3.1 *Algorithms / Procedures*

The CSM was designed and developed in a PC environment using the LabView 5.1.1 software (Labview 1999), which runs in G source programming (graphical icon based programming environment). In order to run the CSM, algorithms were developed to input the weather data, manipulate them, and make an interface with a Fortran-based finite-difference bridge deck model that employs HVACSIM+ (Clark and May 1985).

Mesonet data from several stations in the Woodward area of northwest Oklahoma have been selected for testing the CSM. Woodward was selected as a hypothetical bridge site for this paper because of two reasons. First, the majority of cold-weather fronts that enter Oklahoma pass through the panhandle and northwest Oklahoma and this site is representative of that area. Second, one of the NWS stations, Gage, which is near to Woodward could be used to perform some comparisons.

Currently, the first-generation CSM works on the linear extrapolation of the ambient temperature based on the immediate past history. Forecasted temperature is the primary variable that signals the “on/off” of the bridge heating system. Efforts are underway to improve this extrapolation of temperature using time series analysis.

The smart bridge CSM heavily relies on the remote weather data because the warning and preheating for the bridge are based on the "approach temperature" and the "layer threshold" issued from the weather stations. The approach temperature is defined as the ambient temperature at which a cold-weather warning is issued for any of the remote weather stations monitored by each of the controllers. The layer threshold is a parameter used by the rule-based algorithm that limits a controller from switching on the heating system until a defined number of warning conditions are reported. For instance, if the ambient temperature of a nearby station approaches -1.5 °C (approach temperature) and say 2 out of 3 stations (layer threshold) in the vicinity record -1.5 °C, then the controller system signals for turning on the bridge heating.

In addition to approach temperature and layer threshold, danger temperature, bridge response time, and warn time are three other parameters that guide the rule-based control algorithm. The danger temperature is defined as the ambient temperature measured at the bridge site, below which the bridge heating system must always be operating. Bridge response time is the maximum estimated length of time that the bridge deck heating system should be operating to maintain the setpoint temperature. This parameter defines the efficiency of the control system because if the feedforward controller has been signaling to turn on the bridge heating for a period of time greater than or equal to the bridge response time, then the potential for bridge deck icing was prevented. The warn time is the length of time that the controller for each layer calculates a forecast. If the forecasted temperature drops below the approach temperature within the warn time, a warning is issued indicating that the bridge anticipates heating provided the layer threshold rule is also satisfied. While using the NWS data, the layer threshold parameter will have no effect in the rule-based algorithm because there will be only one station available (i.e., Gage) for testing.

4. RESULTS AND DISCUSSION

The control-module simulation results presented in this paper are primarily based on weather inputs from about 10 Mesonet stations located in northwest Oklahoma. Data from the NWS' Gage station site have also been used to perform some simulation runs of the CSM. In addition, Mesonet data from the Woodward site have been used to validate some sample RDF data for the winter of 1999-2000. Analyses of the NEXRAD WSR-88D and RUC data in the control-module of the GSB project are currently being investigated and no results are ready yet to present in this paper. Precipitation information (especially snow and freezing rain) is obviously important for the GSB project. The second generation of the CSM will incorporate the integrated effects of both precipitation and temperature.

Fig. 2 shows the feedforward simulation results during the period of December 16-27, 1997 using the Mesonet data. The bridge heating system is mostly "on" for most part as long as the average daily temperature is at freezing or near freezing levels.

Fig. 3 shows the feedforward simulation results during the period of December 16-27, 1997 using the NWS data at Gage station. A comparison between Fig. 2 and Fig. 3 indicates the Mesonet's value with a single NWS station in terms of data richness. This can be noticed in the daily average ambient temperature curve and its error bars. Both Figs. 2 and 3 provide some similarity as well as differences in terms of bridge heating. For example, during December 24-26, simulation using the Mesonet data illustrates that the bridge should be on for 100 % of the time, whereas the one using the NWS data illustrates that the bridge should be on for 75-92 % of the time. This change is due to the differences in temporal resolution of data (15-min in Mesonet versus 1-hr in NWS data) as well as the approach temperature values used in the rule-based algorithm of the CSM (0.83 °C using Mesonet data and 0.1 °C using NWS data).

Fig. 4 shows some sample comparisons between Mesonet temperatures at the Woodward site and NWS forecasted temperatures (RDF) for the Woodward region valid for a relatively short-forecast window of 4-11 hours. For the most part, the Mesonet data appear to validate the RDF forecasts (Fig. 4 a). Using a sub-sample of data shown in Fig. 4 (a), a comparison was made between observed data at the Mesonet site and RDF data at forecast windows of 4, 5, 7, 8, 10, and 11 hours for selected dates during December, 1999 (Fig. 4(b)). Fig. 4 (b) shows quite satisfactory results with a few mismatches at both 4-hr and 11-hr windows. Another sub-sample of data for the month of January, 2000 (not shown in this paper) indicated similar results to those shown in Fig 4 (b). RDF forecasts are made two times in a day. The first forecast is made at about 4:30 to 5:00 AM and the second at 4:00 to 4:30 PM local time. In Fig. 4 (b), forecasts at 4, 7, and 10 hours are made in the morning, and 5, 8, and 11 hours are made in the evening. These preliminary results indicate that ambient temperature from the RDF can be used as one of the data sources for the approach temperature and danger temperature in the rule-based algorithm of the CSM even if the temporal resolution of these forecasts are very coarse (3-hr).

Testing the applicability of NWS data and forecast products for the GSB project is an ongoing process, and it is too early to draw conclusions. However, it is clear that forecast and radar information will be important supplements to surface observations, regardless of whether these observations come from a comprehensive state network such as Mesonet, or from the less dense federal network.

5. REFERENCES

Anonymous., 1998: Heated pipes keep bridge deck ice free. Civil Engineering, New York, **68** (1), 19-20.

Brock, F.V., K.C. Crawford, R.L. Elliott, G.W. Cuperus, S.J. Stadler, H.L. Johnson, and
M.D. Eilts., 1995: The Oklahoma Mesonet, a technical overview. *J. Atmos. Oceanic Technol.,* **12**(1), 5-19.

Callihan, B.K., 2000: The design and evaluation of controller for a bridge-deck heated by a geothermal heat pump system. M.S. thesis, Oklahoma State University, Stillwater, 98 pp.

Clark, D.R., and W.B. May, 1985: HVACSim+ building system and equipment simulation program - users guide. National Bureau of Standards.

Elliott, R.L., F.V. Brock, M.L. Stone, and S.L. Harp., 1994: Configuration decisions for an automated weather station network. *Appl. Eng. Agric.,* **10**(1), 45-51.

Ferrara, A.A., and G. Yenetchi., 1976: Prevention of preferential bridge icing using heat pipes, Federal Highway Administration, Washington, D.C, 140 pp. FHWA-RD-76-167, TD 2.30.

Henderson, D.J., 1963: Experimental roadway heating project on a bridge approach. Highway Research Record No. 14, Publication 111, 14-23.

Highway Research Board, 1964: Non-chemical methods of snow and ice control on highway structures. Highway Research Board, National Academy of Sciences, National Research Council, Washington, D.C., 74 pp. NCHRP Report 4.

Labview, 1999: National Instruments, Austin, Texas.

Lee, R.C., J. E. Nydahl, and K.M. Pell, 1986: Design and implementation of a water powered heat pipe system for bridge heating. FHWA-WY-86-002.

Shafer, M.A., C.A. Fiebrich, D.S., Arndt, S.E. Fredrickson, and T.M. Hughes, 2000: Quality assurance procedures in the Oklahoma Mesonetwork. *J. Atmos. Oceanic Technol.*, **17**, 474-494.

6. ACKNOWLEDGEMENTS

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Fig. 2 Bridge Feedforward Simulation using Mesonet Data, December 1997

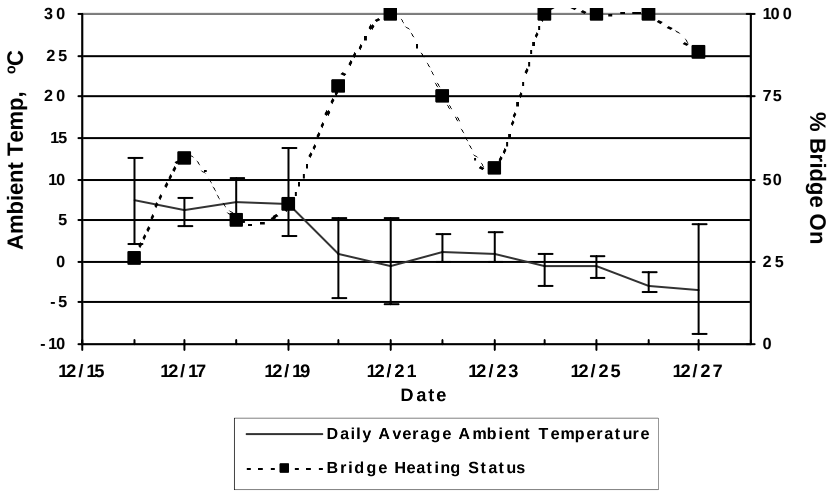

Fig. 3 Bridge Feedforward Simulation using NWS's Gage Station Data, December 1997

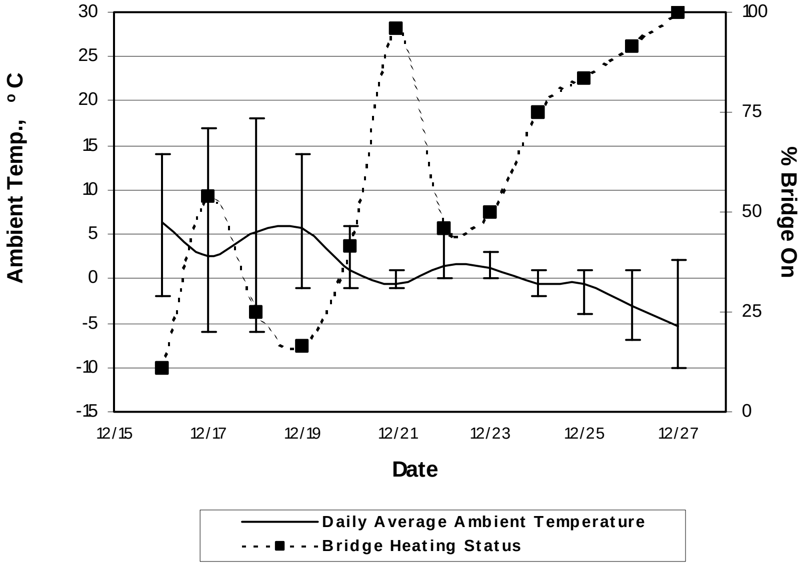

Fig. 4 (a) Forecasted (RDF) Versus Observed (Mesonet) Temperature (4-11 Hours Forecast Window) at Woodward Site for Selected Dates during Winter 1999-2000

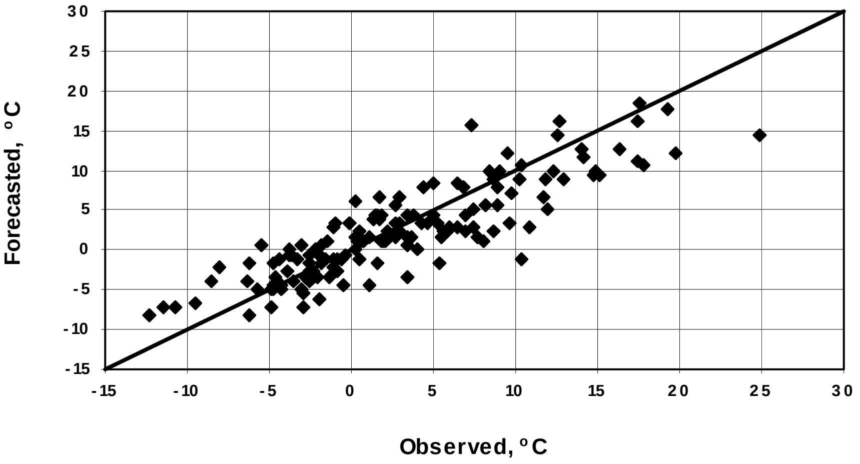

Fig. 4 (b) Observed (Mesonet) and Forecasted (RDF) Temperature for Various Forecast Windows at Woodward (December, 1999)