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GEOTHERMAL HEATING OF BRIDGES IN GLENWOOD CANYON

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16. Abstract

This report presents the general design and cost for incorporating geothermal heating in two bridge decks in the middle of Glenwood Canyon. It is proposed to pipe the goethermal water form the east end of the canyon. Heat pipe heat exchangers can be installed in the cells of the deck. Stainless steel interior pipe is proposed to control corrosion and fouling. Total cost of system is estimated at 1.4 million dollars.

Implementation

Results from this report will be used as an alternative in selecting a method for snow and ice control on high-hazard bridge deck sites.

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BACKGROUND

The design for the interstate highway through Glenwood Canyon calls for numerous bridges, tunnels and winding road. In a few location the roadway is located on the south side of the Canyon which is in the shade throughout the winter. Combining this with long structures on curves which could get preferentially iced in the winter a serious hazard could be present in the winter. Highway officials, therefore, began looking into ways to mitigate the icing hazard in the Canyon.

Colorado is blessed with numerous hot and warm water springs throughout the State. Water temperatures vary from slightly higher than the ground temperature (60 deg.F.) to hot water up to 150 deg.F. These springs could conceivably be used to deice roadways even if the water temperature feels cool (<80 deg.F.). This geothermally heated water is available at both ends of Glenwood Canyon at the surface. There is also some hope that this geothermal water is underground in the middle of the Canyon and can be tapped with wells.

In 1978 the Colorado Highway Department began investigating the use of this geothermal water to control icing of bridges in Glenwood Canyon. (Donnelly[1]) After considering numerous alternatives it was decided to test a bridge deck heating system based on heat pipe technology. In heat pipes a working fluid is vaporized by the heat source at the lower end and the vapor rises to the cold end and condenses. The condensate then runs back down the heat pipe to be revaporized. This process allows transferring of heat over long distances with very little temperature drop. The heat pipe systems allow transferring heat into the deck without running water directly through pipes in the deck, with its associated danger that freeze-up or corrosion will destroy the bridge deck.

Tests with two different heat pipe designs on a mock bridge in Glenwood Springs demonstrated the feasibility of using heat pipes and geothermal water to control ice on bridge decks. Three issues still needed to be addressed before such systems could be utilized in Glenwood Canyon. The first issue was corrosion inside the heat exchangers. Because of the chemicals present in the geothermal water, corrosion and deposition rapidly occur inside the mild steel pipes of the heat exchangers. A coated or corrosion resistant pipe must be used to control this problem. This is being addressed through a research contract with a corrosion specialist at the University of Wyoming[6]. The second issue is: How can these heat exchangers be integrated into the bridge structures and still be consistent with the architectural design of the roadway in the canyon? The third deals with the total cost of such a system and identification of those locations where pavement icing is potentially serious enough to warrant bridge deck heating.

This report will deal with the last two issues. That is, integrating the system into the design of the structures and cost and location of heated areas.

A meeting was held on January 7, 1983 to discuss the use of bridge heating in Glenwood Canyon. It was decided that the areas to be considered for heating will be the structures on the exit sides of the tunnels under Cinnamon Creek and the portal areas of each tunnel. (See Figure 1.) This section of the roadway will be in a pair of tunnels on the south side of the Canyon and the bridges will cross to the north side at both ends of the tunnels. These structures, which will be on curves, will be in the shade most of the time in the winter. In addition, the ones at the west end of the tunnels will have a grade of about 4 1/2 % . It is obvious that icing of these bridges will present a serious hazard during the winter. In order to mitigate this problem 64,000 sq.ft. of heated roadway is required.

INTEGRATING HEATING SYSTEM INTO STRUCTURES

The arrangement of the heat pipe system which is best suited for the structural design, is to locate the evaporator section of the heat pipes inside the cell of the bridge. (The evaporator section is that portion where the water flows through and evaporates the working fluid.) The condenser pipes embedded in the bridge deck can be manifolded together at the lower side of the deck. Each manifold section can service 10 linear feet of bridge deck (one precast segment) before it is connected to the evaporator section mounted inside the cell of the bridge.(See Figure 2.) Each segment of the bridge can contain one complete heat pipe unit and conventional plumbing can be used to connect the pipes together for circulating the geothermal water.

By putting the evaporator section in the cells an offset can be provided every few sections to avoid placing the evaporators at too steep a grade. (See Figure 3.) The grade of the evaporator is limited to about 2% because the high end will become only partially immersed in the working fluid. By placing a tee at every offset instead of an elbow an access can be provided for inspection and maintenance.

The bottom side of the bridge deck within the cell should be insulated with 2-in. urethane foam to minimize heat loss. Foam insulation board could be cast into the wings of the bridge to reduce heat loss. However, the structural problems

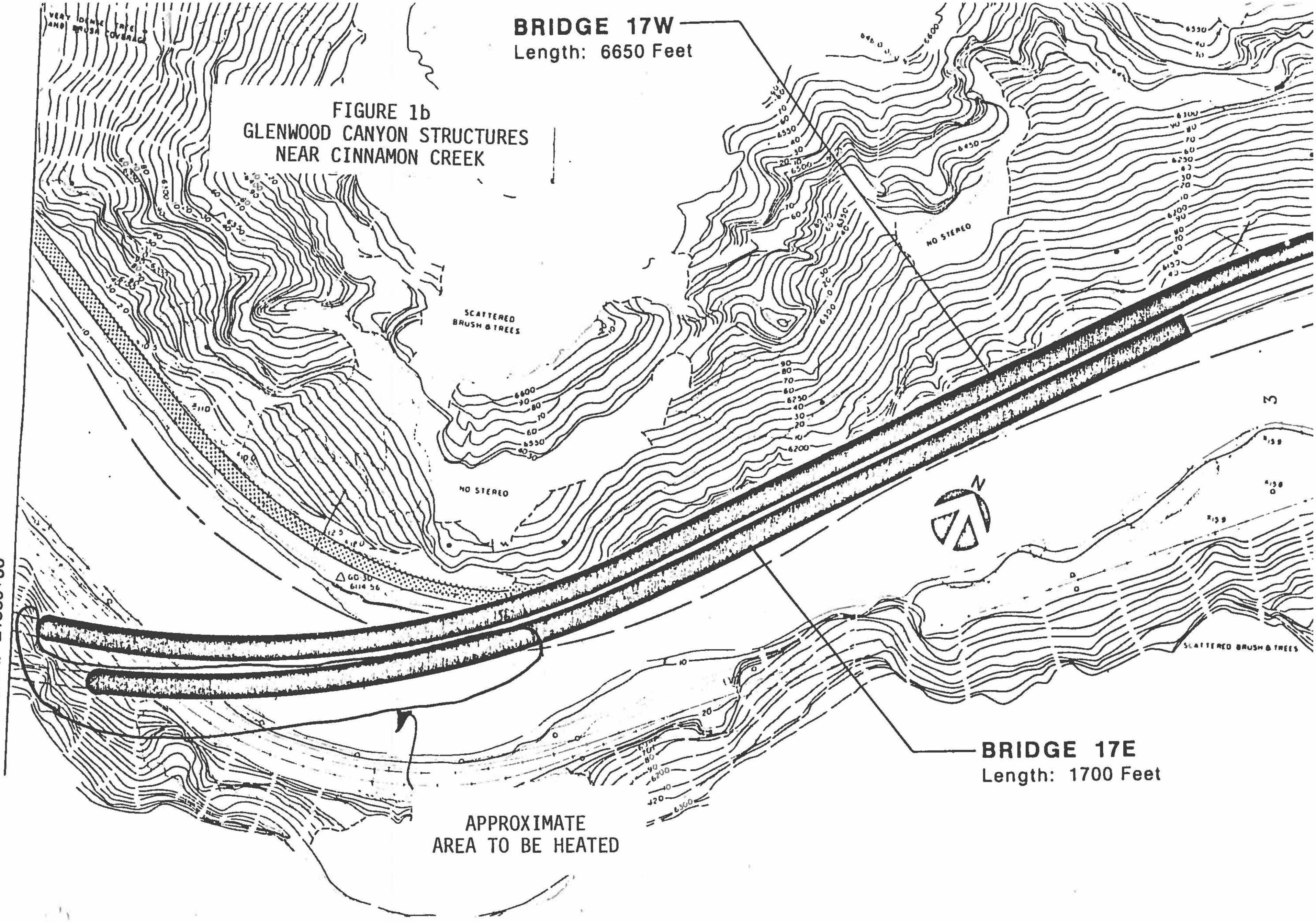


FIGURE 1b
GLENWOOD CANYON STRUCTURES
NEAR CINNAMON CREEK

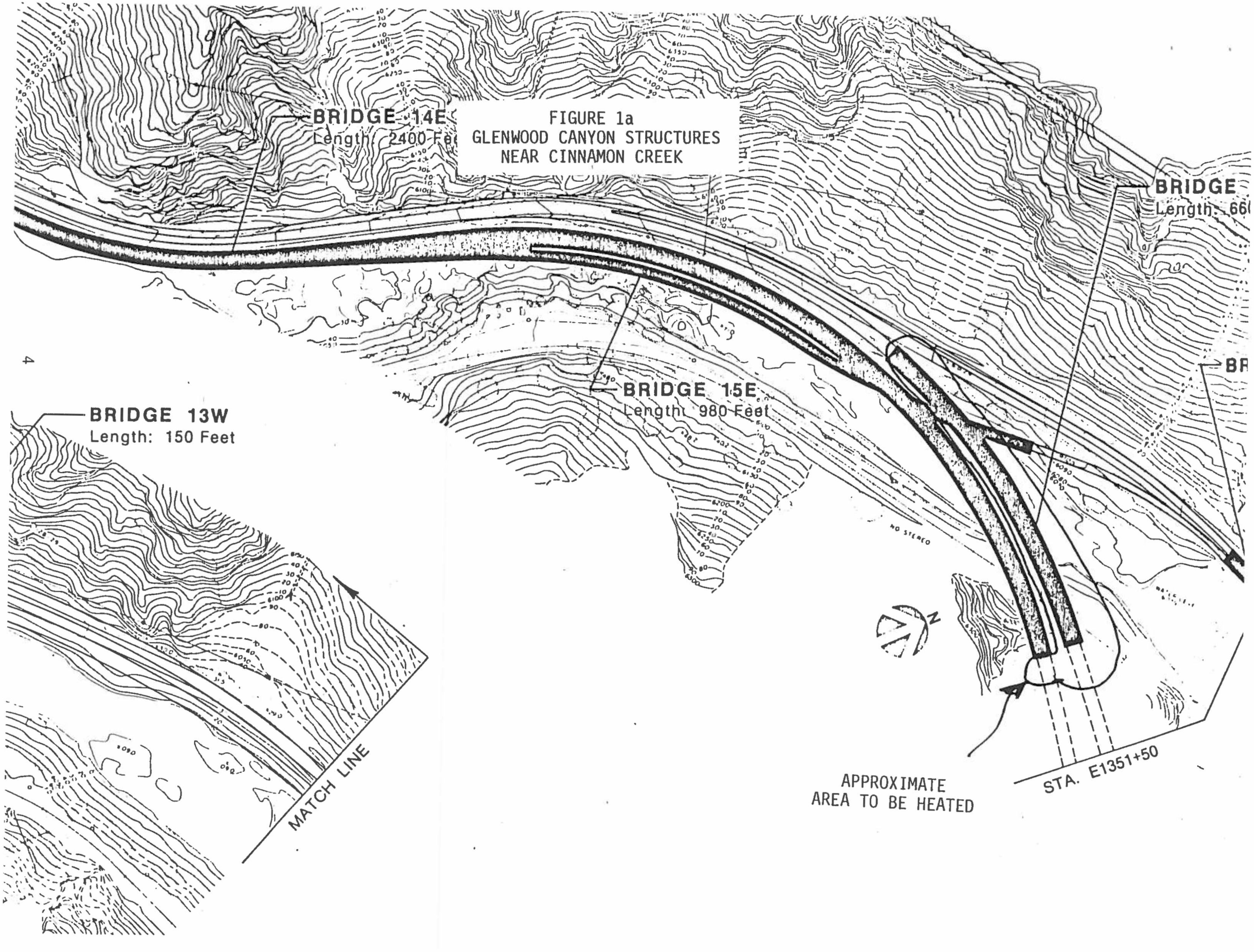


FIGURE 1a
GLENWOOD CANYON STRUCTURES
NEAR CINNAMON CREEK

FIGURE 2

HEAT PIPE SYSTEM IN BRIDGE

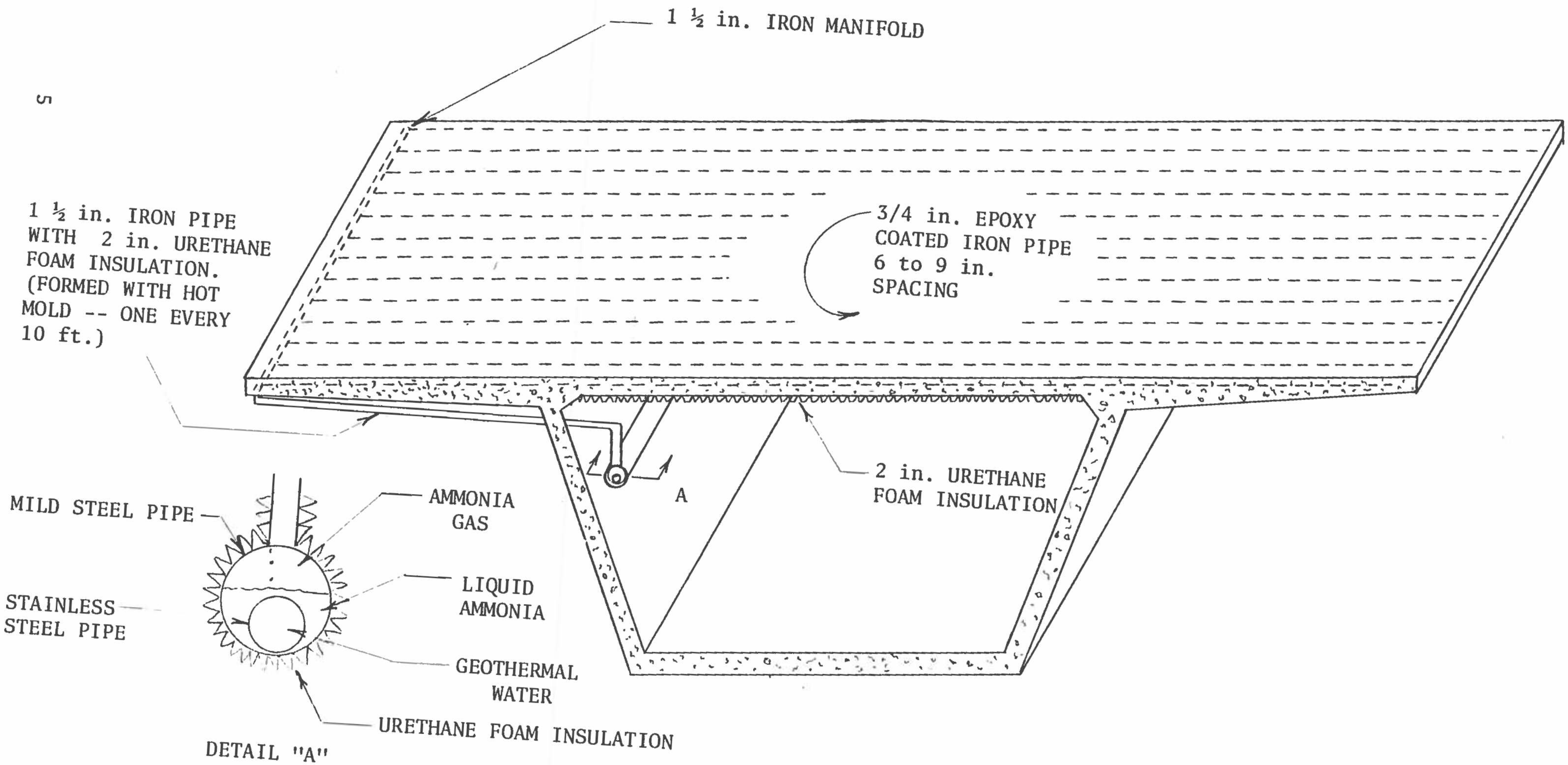
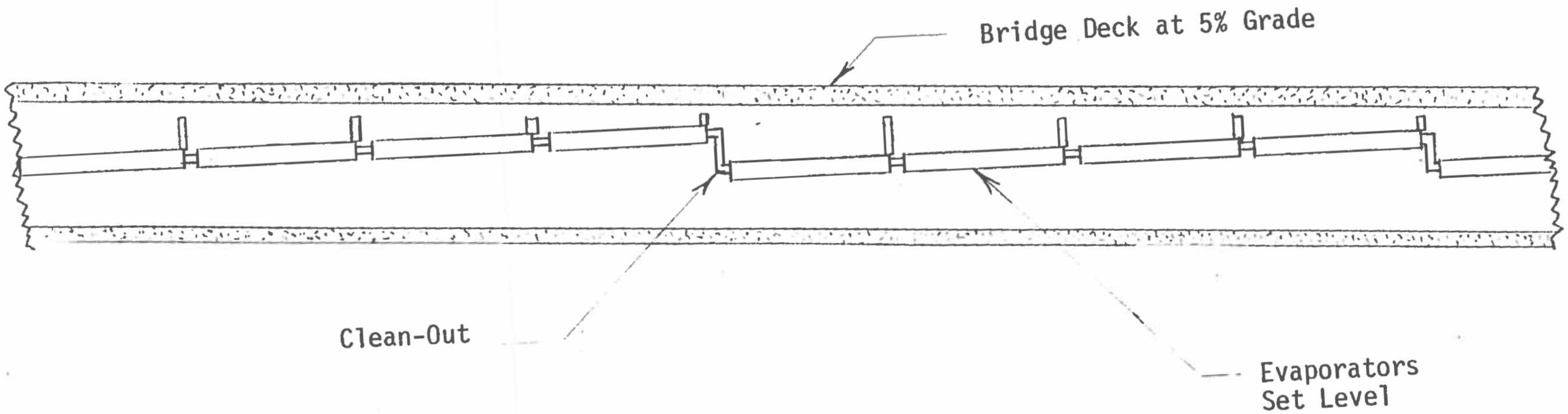


Figure 3
Offsetting of Evaporators inside Bridge Cells



and cost may preclude this method and an alternate approach may be required. Having insulation under only portions of the deck does not mean that there will be uneven melting of the ice. Heat pipes are an isothermal devices which supply the most heat to the coldest part along its length. Uninsulated portions will simply result in an overall reduction in performance which can be compensated for by an increase in the capacity of the system.

Insulation on the evaporator and the manifold will be field produced urethane foam. When external to the bridge the foam can be molded with a hot slip-form that will form a hard durable surface which is resistant to weather and sunlight. Although the resultant color is light brown, paint can be used for better protection and color match.

SOURCE OF GEOTHERMAL WATER

Since the January 7, 1983 meeting it has become increasingly apparent that no geothermal water source will be found near the structures that are planned to be heated. If these structures are to be geothermally heated it will be necessary to pipe the water several miles from an available source. Hot water can be pumped through an insulated pipe for several miles with very little temperature loss. (See Appendix A.)

Swanson[2] indicated that the two closest sources of geothermal water are located at either end of the canyon. The main spring west of the Canyon is used by the Glenwood Springs pool but discharge water would be sufficiently warm for bridge deck heating. Because of the elevation change between the Cinnamon Creek area and Glenwood Springs, pumping costs would be prohibitive. Siloam Springs at the east mouth of the canyon is a better source. Water temperature is sufficiently high (90 deg.F.) and the elevation difference to Cinnamon Creek is only a few feet. The pump would only have to make-up for friction losses in the pipeline and heat exchangers.

According to The Bureau of Reclamation studies a shallow well drilled on the highway right-of-way can be used to tap most of the geothermal water from both of the Siloam Springs. It is estimated that the flow from these springs is in excess of 1000 gal./min.

A 10-inch PVC pipe could be used to make this 28,000-foot journey from the source to the bridges to be heated. The pipe could be insulated with a 2-inch thick urethane foam and the water would only lose 0.5 deg.F. over the entire trip to the bridges. (See Appendix A for calculations.) Pumping 1000 gal.per min. through the system would produce an 82-PSI head loss which can be made up with a 75-horsepower pump. (See Appendix B and C for calculations.)

HEATING SYSTEM REQUIREMENTS

In order to maintain an ice free surface 100% of the time a tremendous amount of heat flux would be required. In fact the most demanding storm during the test period, as indicated by Nydahl[3], would have required around 1100 w/sq.m (100 w/sq.ft.). Installing a heating system with this level of capacity would not be cost effective, in fact, it may produce thermal stress in the bridge that could be stucturally damaging. Nydahl indicated a heating system with 200 w/sq.m (18.6 w/sq.ft.) capacity would maintain an ice free surface during 91 % of the storms.

Based on Nydahl's work a 200 w/sq.m capacity was selected as a reasonable compromise between performance and economics. Seta Corporation[5] indicated that with a 90 deg.F. water source heat pipes with its condenser fingers spaced every 6 to 9 in. would provide this heat flux. Cost of these heat exchangers would be $8.32/sq.ft. when the deck is super-elevated and $9.10/sq.ft. when the deck is perfectly flat. The cost difference reflects the fact that on a flat deck, manifolds must be placed on both sides of the deck to maintain a downgrade in the condenser fingers.

PIPING REQUIREMENTS

In order to distribute the geothermal water to the heat exchangers in the bridges, several miles of plastic pipe are required. Plastic pipe must be used because of the corrosion and deposition problems associated with metal pipe. A 10-in. insulated feeder must be buried from Siloam Springs to the east abuttment of the eastbound bridge just east of the Cinnamon Creek tunnel. At this point the pipe will be run in the cell of the bridge deck. Water is tapped from this pipeline to feed each group of heat exchangers. The size of the feeder pipe will be reduced as water is transferred from the feed line, through the heat exchangers, to the discharge line. Once at the approach to the tunnel the pipes will again be buried through the tunnel and finally enter into the westbound structure at the west portals of the Cinnamon Creek tunnels. Appendix D describes the details of the piping requirements.

COST ESTIMATE FOR GEOTHERMAL HEAT

QNTY.	ITEM	UNIT PRICE	TOTAL
60,000	Heat pipe system with 40 ft. fingers at 6-9 in. spacing	$8.32/sq.ft	499,200
4,000	Heat pipe system with 20 ft. fingers at 6-9 in. spacing	$9.10/sq.ft	36,400
32,000	2 in. Urethane foam insulation on underside of bridge deck within cell.	$1.00/sq.ft	32,000
200	4 in. PVC pipe run in bridge	$7.00/ft	1,400
800	6 in. PVC pipe run in bridge	$10.00/ft	8,000
7,000	8 in. PVC pipe run in bridge or trench	$12.00/ft.	84,000
27,100	10 in. insulated PVC pipe run in bridge or trench	$22.50/ft.	612,000
3,000	2 in. urethane foam insulation for feeder pipe (.5 cu.ft/ft)	$6/cu.ft.	9,000
1	1000 gal/min pump		4,000
1	Pumphouse and elec. service		10,000
	Contractor profit (10%)		130,000
TOTAL CAPITAL COST - - -			$ 1,426,000

IMPLEMENTATION

As a final check of the performance of the heat exchanger system, one section of the manifold should be purchased and operated near Siloam Springs for a short period of time. This will provide a final check of the system design.

Much research and testing have gone into this design but the complete resultant system has never been tested. The eccentric manifold system and the stainless steel have both been tested individually with Glenwood Springs geothermal water. But, the stainless steel as part of the heat exchanger has not been tested. In addition, performance testing with Siloam Springs water has not been conducted. It is important to check the corrosion and fouling of the stainless steel in this water because the chemical compositon and temperature are slightly different from that used in the Glenwood Springs testing.

Enough development of the well will have to be done to provide 100 gal./min. for the heat exchanger. Cost would probably run between 10 to 20 thousand dollars and could be included in the next available construction project.

The decision on whether or not to heat these bridges should be made before the design of the structures start. The pipeline installation should be included in the contracts which contains the bike path construction to facilitate burying the pipeline.

References

1. Donnelly, D. E.: Geothermal Energy for Snow and Ice Control; November, 1981; CDH-DTP-R-81-13; Colorado Department of Highways

2. Swanson, H. N.; Evaluation of Geothermal Energy for Heating Highway Structures: May, 1980; CDH-DTP-R-80-6; Colorado Department of Highways

3. Nydahl, John, and Others; Data Collection and Analysis for Geothermal Research; August, 1981, CDH-UW-R-81-11; University of Wyoming and Colorado Department of Highways

4. Griffin, R.G.; Highway Bridge Deicing Using Passive Heat Sources; October 1982; CDH-DTP-R-82-7; Colorado Deartment of Highways

5. Seta Corporation; A Heat Pipe System for Glenwood Canyon Structures; June 25, 1984; Proprietary report prepared for internal use of the Colorado Deartment of Highways; Seta Corporation, Laramie, Wyoming

6. Barton, K. R.; Corrosion Resistance of Materials for Geothermal Heat Exchangers; May 1985; CDH-UW-R-85-8; University of Wyoming and The Colorado Department of Highways.

Appendix A

Heat Loss Calculation for Supply Pipeline

Assume 10 in. diameter pipe
with 2 in. thick polyurathane
foam insulation for 28,000 feet.

Nominal 10-in. pipe has 10.75 in. outside diameter resulting in 2.8 sq. ft. per lineal foot of pipe. The 28,000 ft. of pipe then has 78,400 sq. ft. of surface area. Since 2 in. thick urathane foam insulation has a R-factor of 13, 78,400/13 = 6031 BTU/hr.°F will be lost. For a temperature difference of 40°F (90-50) total heat loss is 241,000 BTU/hr or 4021 BTU/min. With 1000 gal/min of flowing, each gallon of water will lose 4.02 BTU and since the specific heat of water is 1.0 and its density is 8.35 16/gal., the water will lose .48°F during the trip.

Appendix B

Friction Loses in Geothermal Plumbing

Based on the nomograph on page 6-39 of reference 1, the friction lose for a 10-in. pipe flowing with 1000 gal/min. with a roughness factor of .010 is .005 (or .5 feet per 100 feet of pipe). With the 25,500 feet of underground, 2,400 ft. in the bridges, and 3100 ft. in the tunnel, the total pipeline will be 31,000 ft. The total friction lose in the pipe is therefore, 155 feet or 67 PSI. An addition 15 PSI pressure drop is expected in the heat exchanges (Reference 2) for a total friction lose of <u>82 PSI</u>.

Appendix C
Pumping Requirements

Eighty-two PSI was calculated as the friction lose, but for design purposes 100 PSI will be used. The power required to pump 1000 gal/min. at 100 PSI is given as follows:

$$P = \frac{(100\ \text{PSI})\quad(1000\ \text{gal/min})\quad(8.35\ \text{lb/gal})\quad(1\ \text{H.P.})}{(.43\ \text{PSI/ft.})\quad(60\ \text{sec/min.})\quad(.85^{*})\quad 550\ \text{ft-lb/sec}}$$

$$P = \underline{69.2\ \text{H.P.}}$$

*.85 is the expected effeciency of a pump this size. Ref. 1. page 8-74.

This will require a 75 H.P. Pump.

Appendix D

Piping Requirements

Siloam Springs to Bridge Feed Pipe

Length:	26,000 ft.
Alignment:	Under bike path
Time:	Before bike path construction
Pipe:	10 in. Sch 40 PVC
Pressure:	100 to 45 PSI
Temperature:	90° F
Insulation:	R-13 waterproof (2 in. urethane foam)
Soil Conditions	Loose rocky fill (minus 6 in.)

Feeder pipe within Structure

Length:	1800 ft-10 in/ 200 ft.-8in/ 400ft.-6in/
Alignment:	Within Cell of Bridge
Time:	After bridge construction
Pipe:	10, 8, and 6 in. Sch 40 PVC 4 in. Tees every 200 ft.
Pressure:	45 to 35 PSI
Temperature:	90°F
Insulation:	R-13
Soil Condition	N.A.

Feeder Pipe Through Tunnel

Length:	3,300 ft.
Alignment:	Through Cinnamon Creek Tunnel (Share trench with drain pipe)
Time:	During tunnel constuction
Pipe:	8 in. Sch 40 PVC
Pressure:	45 - 40 PSI
Temperature:	90°F
Insulation:	R-13 waterproof (2 in. urethane foam)
Soil Condition	Hard rock

Drain Pipe Within Structure

Length:	600ft.-10 in./200 ft.-8 in./600ft.-6 in.
Alignment:	Within cell of bridge
Time:	After bridge construction
Pipe:	10, 8, and 6 in. Sch 40 PVC 4 in. tees every 200 ft.
Pressure:	40 to 20 PSI
Temperature:	90°F
Insulation:	None
Soil Condition	N. A.

Drain Pipe Through Tunnel

Lenght:	3,300 ft.
Alignment:	Through Cinnamon Creek Tunnel (Share trench with feed pipe)
Time:	During tunnel construction
Pipe:	8 in. Sch. 40 PVC
Pressure:	30 PSI
Temperature:	90°F
Insulation:	None
Soil Condition	Hard Rock

Appendix E

Power Requirements

A 75 H.P. motor will operate at approximately 90% efficiency therefore the power consumption will be:

$$P = \frac{(69.2\ \text{H.P.})\ (.746\ \text{KW/H.P.})}{.90}$$

P = 57.4 Kilowatts

Electrical Cost

12	Monthly service charge 14.01	$ 168
348	Monthly demand charge 10.03/KW	3,490
248,000	Energy Charge $.01944/KW Hrs.	4,821
	Fuel cost adj $.005/KW hrs	1,240
	Annual Electric Bill	$9,719

Present Value of 20 years of Bills is (x 13.59) $132,100

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