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A Report on the Investigation of the Causes of Corrosion in the Radiant Heating System at the Truckee Maintenance Station

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I. Introduction

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The purpose of the survey was to determine the cause of corrosion of the black iron pipe forming the radiant heating system in the concrete floor of the equipment garage.

Historically, the Truckee Maintenance Station was constructed in 1954. Approximately one year after construction, a leak in the radiant heating system was detected.

From the observations of the maintenance forces at the station, there appears to now be two or more additional leaks in the piping cast in the concrete floor slab.

During the week of October 14, 1957, the Materials and Research Department carried out the requested survey of the radiant heating system. The purpose was to determine the probable cause of corrosion and to recommend an effective and economical method of dealing with the problem.

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
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A REPORT ON THE INVESTIGATION OF THE CAUSES OF CORROSION IN THE RADIANT HEATING SYSTEM AT THE TRUCKEE MAINTENANCE STATION

57-15

October 18, 1957

MATERIALS & RESEARCH DEPARTMENT

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State of California
Department of Public Works
Division of Highways
Materials and Research Department

October 18, 1957

Corrosion Investigation
Truckee Maintenance Station

Lab. Proj. Auth. 100-S-6127

Mr. Alan S. Hart, District Engineer
District III
Marysville, California

Attention: Mr. R. I. Nicholson, Dist. Maint. Engr.

Dear Sir:

Submitted for your consideration is:

A REPORT ON THE

INVESTIGATION OF THE CAUSES OF CORROSION

IN THE RADIANT HEATING SYSTEM AT THE

TRUCKEE MAINTENANCE STATION

Study made by . . . . Structural Materials Section
Under general direction of . . . . J. L. Beaton
Under general supervision of . . . . L. S. Hannibal
Work supervised and report prepared by . . . . . R. F. Stratfull

Very truly yours,

F. N. Hveem
Materials and Research Engineer

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I. INTRODUCTION

On October 9, 1957, Mr. R. I. Nicholson, District Maintenance Engineer, requested by letter that the Materials and Research Department perform a corrosion survey at the Truckee Maintenance Station.

The purpose of the survey was to determine the cause of corrosion of the black iron pipe forming the radiant heating system in the concrete floor of the equipment garage.

Historically, the Truckee Maintenance Station was constructed in 1954. Approximately one year after construction, a leak in the radiant heating system was detected.

From the observations of the maintenance forces at the station, there appears to now be two or more additional leaks in the piping cast in the concrete floor slab.

During the week of October 14, 1957, the Materials and Research Department carried out the requested survey of the radiant heating system. The purpose was to determine the probable cause of corrosion and to recommend an effective and economical method of dealing with the problem.

II. SUMMARY AND CONCLUSIONS

The field corrosion survey of the concrete embedded radiant heating system is the result of macro-galvanic corrosion.

The macro-galvanic corrosion is due to de-icing salts filtering through curing cracks, paving joints, and the natural voids in the concrete to the steel pipes of the heating system. The differential concentrations of de-icing salts and moisture are causing corrosion cells to function.

The continual washing during routine maintenance of the concrete slab with water has the effect of maintaining the moisture content of the concrete at a harmful level. Moist concrete is a conductor of electricity which will permit macro-galvanic corrosion cells to function. At the present time, there appears to be sufficient salt present in the concrete to overcome the normal corrosion inhibiting effect of the concrete. The concentration of salts combined with the leaking pipes is accelerating the corrosion.

There are two positive methods of corrosion control available for consideration.

The first method is cathodic protection, which is not recommended.

The second, the recommended method of corrosion control, is to replace the heating system, correcting the faults of the present system.

There is also an experimental method of corrosion control which is offered for consideration, but as will be discussed the results of this method are not predictable. This experimental method is described only as a matter of information, as it would require material changes in the existing operating procedures of the station.

III. RECOMMENDATIONS

1. That the present radiant heating system be removed and a new system be installed. (See Discussion, V(F))

2. That the new installation of a radiant heating system be accomplished in the following manner:

   a. The piping system shall be copper pipe.

   b. The piping system shall be wrapped with a dielectric tape, or coated with an epoxy resin or other suitable type of moisture resistant coating.

   c. The coating applied to the piping shall be electrically tested after being placed, but prior to the concrete pour. This is to detect "holidays" or breaks in the coating.

   d. Electrical insulators shall be installed in the riser pipe of each bank of coils, isolating each bank from the system.

   e. Wire mesh or bar reinforcing steel shall not be electrically or mechanically connected to radiant heating piping. Construction chairs, if used, should be concrete or some other nonconducting material.

   f. The concrete slab shall be constructed in one "lift".

   g. The piping shall have a minimum clearance top and bottom of 2" of concrete between the outside of the piping and the surfaces of the new concrete.

   h. The top, or wearing surface, of the concrete slab shall be coated with a durable and moisture repellent material such as Epoxy Floor Enamel (Amine Curing Type) which may be obtained from Boysen Paint Company, 42nd and Linden Streets, Oakland, California.

   i. The coating on the top, or wearing surface, shall be maintained as a moisture repellent membrane.

3. As discussed in V(E), one of the several radiator sealing compounds now on the market could be used to temporarily stop the leaking of the system during this winter.

IV. TEST DATA

A. Potential Measurements

The discharge of electrical current from a corroding structure can be detected by measuring the potential, or voltage, rise in the electrolyte.

By means of a high impedance voltmeter and a standard coppersulfate half-cell, the existing piping system was checked for any galvanic current discharge or accumulation.

The results of this potential survey are shown on Exhibit I, Equipotential Contours.

There are 17 locations marked on the map with a "C" to designate a corroding area.

Insofar as the potential contours are indicative of potential gradients, it does not necessarily follow that all of the steel within the solid lines denoting corroding potentials is suffering from active corrosion, rather they mean that the area is potentially subject to corrosion.

B. Salts in Concrete

Specimens of concrete were removed from the floor in two locations: Location No. 1, near the doorway in northerly bay No. 10 had a .03% NaCl in the concrete from the top of the slab to a distance of 2" below the top of the floor. Another sample from the same location which went from 2" to 3 3/4" below the top of the floor had .02% NaCl.

The concrete in Location No. 2, which was near the drain in the southerly bay No. 21, had the following salt concentration: .02% NaCl from the top of the floor to 2" below the surface, and .03% NaCl from 2" below the surface to 3 3/4" below the surface.

The salt concentrations are in percent of total weight of the sample and indicate that sufficient salts are present in the concrete to overcome the corrosion inhibiting effect of the concrete.

The chemical analysis of the concrete indicates that there is less than .01% of sulfates, therefore $SO_4^{=}$ is not a consideration in the present corrosion problem.

C. Test of Possible Cathodic Protection

Basically, impressed current cathodic protection of a piping system is accomplished by electrically forcing the piping system to become a non-corroding electrode. An expendable electrode is substituted for the corroding areas on the piping to accomplish the electrical protection procedure.

A test was made to determine the amount of current required to bring the system under cathodic protection. A steel chain was laid on moistened rags upon the concrete floor. 135 volts were then applied between the steel chain anode and the piping system.

With a current flow of 70 milliamperes, steel pipe and wire mesh reinforcing within a distance of 10 square feet of concrete surface were brought under cathodic protection. By computing the total number of square feet of encased piping and wire mesh reinforcing, it is indicated that 74 amperes of current and approximately 100 volts would be required to bring the heating system in the garage under cathodic protection. The high voltage is required because of the high electrical resistance of the natural soil and the limited number of available anode locations.

This high voltage required makes cathodic protection impractical.

V. DISCUSSION

A. Corrosion Causes

1. Electrochemical Corrosion

The fundamental cause of any metal corrosion is galvanic action, which is generally classed as being either micro or macro in character. A corrosion cell can be formed by differences in concentration or composition of an electrolyte, which in this case is wet concrete containing sodium chloride.

Micro-galvanic corrosion is generally considered a type of corrosion which occurs from contact with the atmosphere or by "soil action". In micro-galvanic corrosion, the complete corrosion cell may be contained within the area of a single raindrop. The electrical currents which flow are feeble and are usually manifested by a general corrosion attack.

However, in macro-galvanic corrosion, the corrosion cell can extend for many miles, such as on a pipeline. In this type of corrosion, it could be said that all the feeble electrical currents of an atmospheric type of micro-galvanic corrosion cell are added up and directed to one small area of attack. The general result of this type of corrosion is deep pitting or etching of the metal.

2. Method of Construction of Present Radiant Heating System

The present heating system was constructed in the following manner:

a. A floor slab four inches thick was placed.

b. Black iron pipe was placed on top of the slab.

c. 6 x 6 wire mesh was tied in place on top of the pipe coils.

d. A three inch slab was then poured on top of the bottom slab to encase the heating system.

This method of construction should present a durable and satisfactory installation if the environment was such as to be expected in an office or other use where salts and water were not coming in repeated contact with the concrete.

Apparently, construction joints, incidental cracks, or other openings in the concrete floor have allowed salts

to penetrate to the non-bonded area between the first and second layer of concrete. It is the deposition of these salts in contact with the steel in this non-bonded area that is causing the distress.

Additionally, the placing of the wire mesh on top and in contact with the piping has accelerated the corrosion of the piping. The probable reason is that the wire mesh is in concrete of less moisture and salt content and thereby sets up a corrosion cell between itself and the steel in high salt and moisture content areas.

3. Corrosion in the Radiant Heating System

The corrosion in the radiant heating system is macro-galvanic in nature. This type of corrosion of steel in salt-laden concrete is very difficult to contain once it becomes as aggressive as it is at the Truckee Station.

Washing of the floor with water not only causes the corrosion to occur, but also accelerates the rate of corrosion. In addition, leaks in the system which now exist are increasing the corrosion rate as well as causing corrosion to occur in areas that were not corroding prior to the leaks.

At the present time, there is no known method of removing or neutralizing the salts in the concrete, nor is there any known method of removing salt-laden corrosion products except by exposing the pipe and sandblasting. Salt-laden corrosion products on steel will cause the corrosion attack to continue even if all the salt could be removed from the concrete.

B. Anticipated Leaks

One leak was repaired after one year of service at the garage. At the present time, the maintenance forces state that there are now two, or more, additional leaks in the system.

The incidence of leaks up to this time is not sufficient to permit plotting a leak frequency curve to estimate the number of leaks which can be anticipated in the future.

However, Exhibit I, Equipotential Contour Map, indicates that there are at present at least 17 locations where the piping or wire mesh reinforcing, or both, are suffering from a corrosion attack, and it may be assumed that leaks will develop in these areas sooner or later.

C. Corrosion Control

There appear to be two methods of corrosion control available for consideration.

1. Cathodic Protection

The first method is cathodic protection by impressed currents, which is not recommended.

If cathodic protection were to be applied so that there will be a minimum danger of causing corrosion on adjacent private piping systems by stray currents, the anodes would have to be placed underground beneath the drain in the center of the garage.

The voltage required to force approximately 75 amperes of current would be in the neighborhood of 100 volts. Not only would this high voltage endanger adjacent privately owned buried structures, but there is the definite possibility that reinforcing steel not electrically interconnected to the system would be caused to corrode.

Also, for these high current densities, the life of the artificial anodes would be short, necessitating replacement in less than ten years.

2. Experimental Corrosion Control

An experimental method of corrosion control, as outlined below, could be exercised at the station. However, the results are not fully predictable because of the accelerated operating procedures at the station. Therefore, this method is not recommended for the Truckee Station.

In general, this method of corrosion control would first require that ALL of the leaks in the system be stopped. This could be accomplished by exposing leaking coils by breaking the concrete or by introducing liquid solders (similar to those used in automobile radiators) into the system. The introduction of a liquid solder may require a low water pressure regulation of the radiant system.

ALL of the concrete cracks and paving joints would have to be thoroughly sealed to prevent free water and de-icing salts from flowing into the unbonded surface in between the two slabs.

Washing of the slab would have to be discontinued. Dry cleaning methods of sweeping would have to be used.

Electrical insulators would have to be installed on the riser pipe of each coil to prevent corrosion cells from forming between the north and south banks of heating coils.

In general, it will be noted that this method of corrosion control involves the exclusion of moisture from the concrete surface. During the winter at the Truckee area, it

is doubtful whether the concrete is ever dry, as the snow plows and trucks which have been exposed to snow and rain are brought into the building for washing; therefore, moisture will be in continual contact with the floor. This method of containing the corrosion does not hold much promise for success as it will in effect be trying to control a non-controllable environment.

3. Replacement

The only other suggested method of corrosion control is to abandon the present system and replace with a new installation.

D. New Construction of a Radiant Heating System

If the District elects to construct a new radiant heating system, the following manner of construction is suggested for either copper or black iron pipe placed in this or any other installation subject to an equally severe environment:

1. The piping should be coated with an epoxy type paint 5 mils or greater in thickness. Any other type of coating, such as plastic tape, asphalt, or tar dipping and wrapping, should not absorb moisture. All pipe coatings should be field checked for dielectric continuity by electrical testing devices.
2. The slab should be constructed in one continuous pour so that the heating system is encased in a continuously bonded concrete slab.
3. The top, or wearing, surface of the concrete should be coated with an epoxy type or other moisture resistant coating.
4. All radiant heating coils should be electrically insulated from each other and from reinforcing steel or other buried metallic objects.

The reasons for the suggested type of construction are the unusually severe environmental conditions involving the presence of salts and intermittent wetting.

The following are the reasons for the various items and details of the suggested construction method:

1. Continuously Poured Slab

A continuously poured slab will eliminate non-bonded surfaces which might collect water and salts.

2. Coating of Piping

Coating of the piping will prevent or at least reduce the formation of macro-galvanic corrosion cells. The

coating will prevent the steel in non-salt areas of concrete from accelerating corrosion of steel in the high salt and moisture areas. The reason for this is that the coating will electrically insulate the pipe from the concrete and thereby stifle its action as a cathode. The only type of corrosion which will then be formed will be micro-galvanic, such as found in atmospheric corrosion. This type of corrosion will be less severe and can be controlled by normal repair methods. The piping in the Truckee Station type of environment should be of copper.

3. Coating of Floor

The coating of the floor will reduce the quantity of salt-laden moisture from coming in contact with the concrete surface, thereby reducing the probability of differential moisture and salt concentration.

4. Wire Mesh Reinforcing

Wire mesh reinforcing is an additional cathodic area which will accelerate corrosion when electrically coupled to the black iron piping. Conversely, when wire mesh reinforcing is electrically connected to copper pipe, the mesh may be caused to corrode due to the galvanic couple of copper and steel.

Wire mesh reinforcing may be used in the new slab provided extra precautions are taken to assure that there will be no contact between it and the piping or any metal of the system. For instance, construction chairs should be concrete blocks rather than of steel.

If the existing lower floor slab is left in position, it will probably not be necessary to use reinforcing steel in the new slab. This would be advantageous.

E. Corrective Action by the District

The poor condition of the radiant heating piping in the Truckee Station does not appear to be a problem which could affect the safety of the personnel or the structural stability of the building. It therefore appears that the operations of the station during the winter months need not be interrupted by new construction.

Water leaks in the system, other than being bothersome and accelerating the corrosion rate, will not affect the safety of the boilers. The maintenance personnel stated that there is an automatic valve in the boiler system which will replenish lost water in the heating system from the utility lines.

If the water pressure is not too great, the introduction of a liquid solder into the radiant heating system may slow or stop the present rate of water loss. A trial use of liquid solder should determine whether the existing pressures are too great for the solder's "plugging ability". A water pressure regulator valve probably exists in the system. If not, one could be used to lower and control the pressure if the liquid solder will not function under the existing water pressure.

It appears that there are two possible methods of replacing the heating system: (1) to abandon the present system and place a new slab on top of the existing floor, or (2) remove the existing top slab and piping and replace with a new slab. (The entire slab could also be removed.)

The first alternative is not recommended as the existing heating coils will probably continue to corrode and crack the slab containing them. This cracking will certainly endanger the new slab.

The only completely safe procedure will be to remove all concrete that may contain any salt.

VI. APPENDIX

Inspection of Tahoe Maintenance Garage

As a comparison to the Truckee Maintenance Station floor, potential measurements were made during the week of October 14, 1957, of the floor of the Tahoe Maintenance Station. The results of this survey are shown on Exhibit II, Equipotential Contour Map.

As indicated by the potential survey, the steel wire mesh reinforcing is corroding. The corrosion of this steel is causing cracks to be formed in the concrete slab.

There are three fundamental reasons for the corrosion of the wire mesh reinforcing: (1) the storage of de-icing salts, (2) the electrical contact of the steel mesh to the copper piping, and (3) moisture.

The stored de-icing salts are not only attacking the concrete surface, but are leaking through the concrete to the steel. The corrosion of the steel is greatly aggravated by the galvanic couple of dissimilar metals, copper, and steel.

Distress is not manifested as greatly in the Tahoe Station as in the Truckee Station, as corrosion in the Truckee Station concentrates on the pipes and results in leakage of water, and the leakage of water is accelerating the corrosion.

It is suggested that the de-icing salts be removed from storage within the garage. At least the salt should be stored in such a manner that it will not affect the corrosion inhibiting properties of the concrete.

The de-icing salts could be stored on a platform in the garage area, but precautions must be taken so that spillage of the salts will not come in contact with the floor.

The washing of the floors or trucks inside of the building with water should be discontinued at the Tahoe Station.

There is a good possibility that the removal of the salts from storage in the garage, combined with the discontinuance of wetting the floor, may control any further cracking of the floor. However, all of the existing cracks and construction joints should be sealed to prevent the free access of water. The floor should <u>not</u> be coated.