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POLYMER IMPREGNATION OF A CALIFORNIA BRIDGE DECK

D.L. Spellman, J.H. Woodstrom and R.J. Spring

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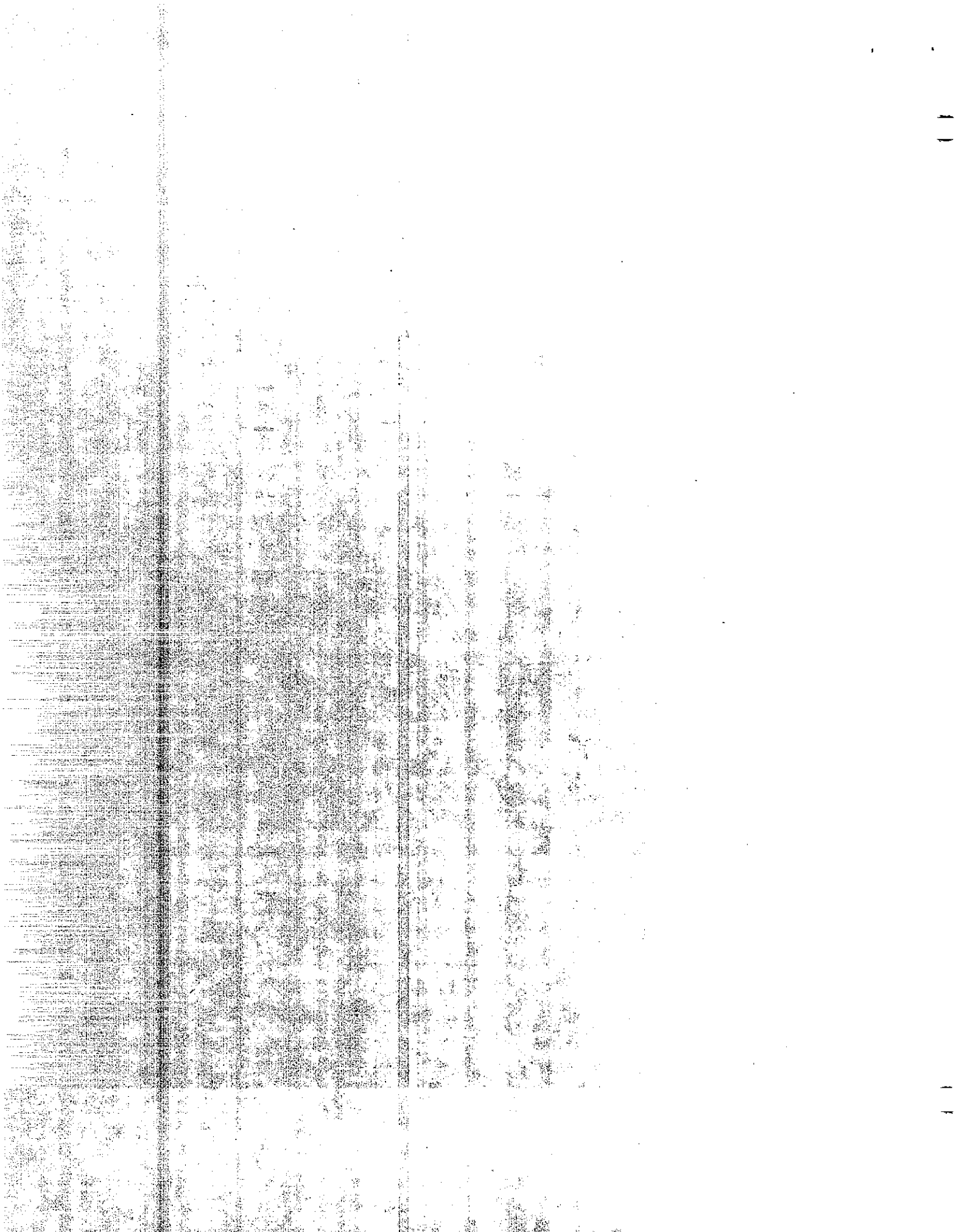

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INTRODUCTION

A major problem facing highway departments throughout the country is that of the deterioration of reinforced concrete bridge decks as a result of corrosive action on the reinforcing steel. Deck deterioration is attributed to the practice of applying "de-icing" salts to prevent moisture from freezing to the bridge decks, thus aiding in the removal of the snow and ice. The chloride penetrates into the surface of the concrete and eventually reaches the reinforcing steel. Over a period of time the chloride concentration increases and the reinforcing steel corrodes. Expansive forces created during this corrosive process are exerted on the surrounding concrete and eventually the surface cracks and spalls. Resulting damage often necessitates a major repair or even the replacement of the entire deck.

This type of deck deterioration can be prevented if the concrete surface can be sealed from the intrusion of salts. A considerable research effort has been expended on developing deck seal systems with varying degrees of success. One of the newer more recent approaches is that referred to as "polymer impregnation". This involves impregnating the concrete surface with a liquid monomer, allowing the monomer to penetrate into the concrete, and later obtaining in-situ polymerization of the monomer. Theoretically the result is that the voids and capillaries of the concrete become filled with polymer, thus preventing the chlorides from penetrating to the reinforcing steel.

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Much of the early developmental work involved in combining the field of plastics with that of highway concrete was done by Brookhaven National Laboratories and the Federal Highway Administration(1,2,3,4).

In October 1974, the Bureau of Reclamation conducted a field research project involving the polymer impregnation of an entire bridge deck near Denver, Colorado(5). Based on the successful results achieved from that project, it was determined by the FHWA that polymer impregnation was a potentially feasible means of providing a protective seal against chloride penetration. Before the basic technique for polymer impregnating an entire bridge deck could be considered fully operational, additional experimental field test sections needed to be constructed. Hopefully these sections, involving entire bridge decks, would provide information in such areas as cost, technique, and suitability.

California had previously conducted a laboratory investigation to develop a workable system, as well as the technique required to successfully achieve impregnation under field conditions. This monomer system and technique were successfully tested by impregnating a 90 foot x 8 foot (27.4 m x 2.4 m) section of an actual bridge deck near Sacramento during the fall of 1974(6).

Included in this operation were:

1. Selection of the monomers and catalysts and their proper proportions.

2. Development of a process to dry the upper 2 inches (50 mm) of the deck.

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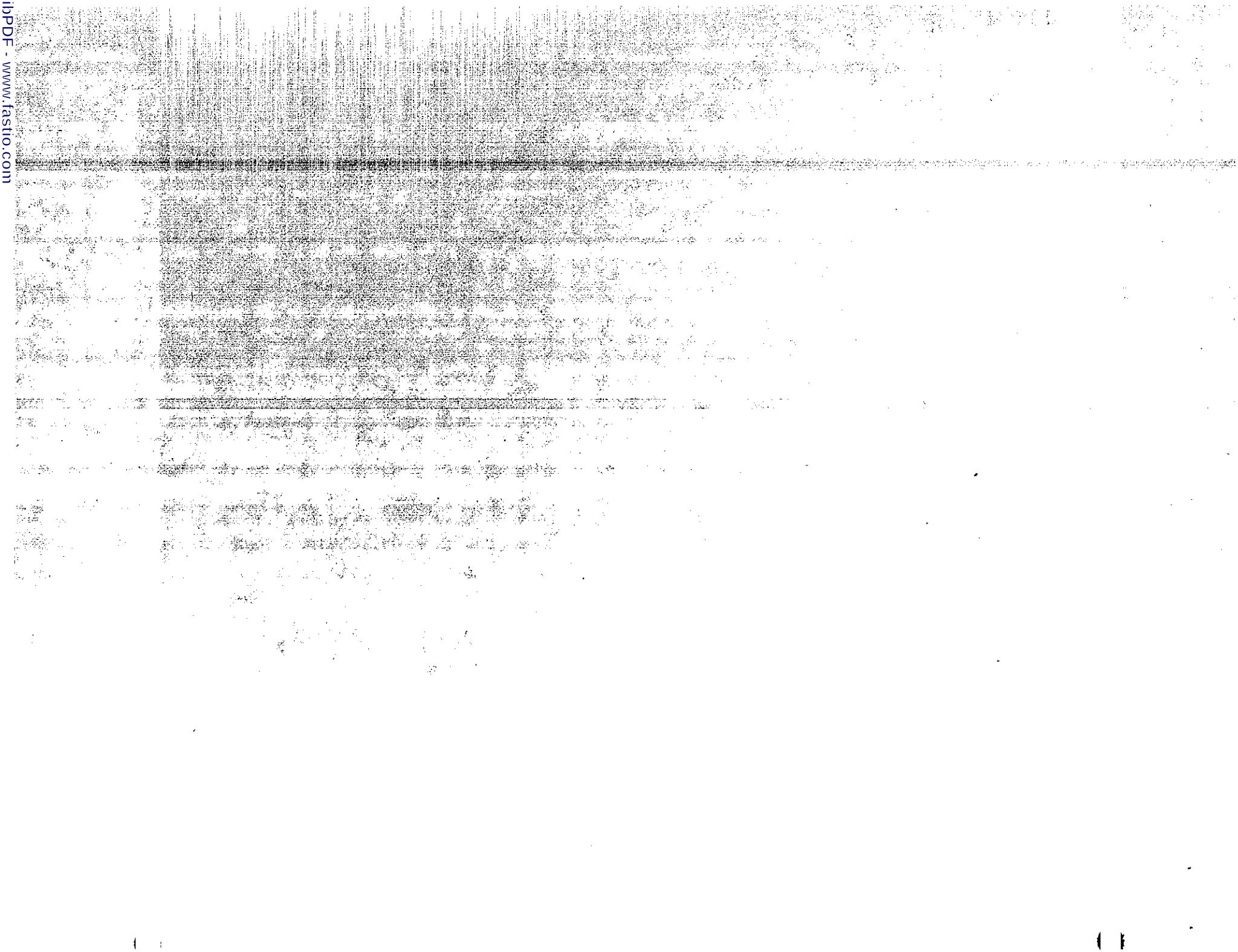

3. Application of the monomer system and retention for the proper length of time to assure impregnation.

4. Application of heat to polymerize the absorbed monomers.

This research reported herein was performed to provide additional information and further evaluate the feasibility of using polymer impregnation on newly constructed concrete bridge decks as an economical means of preventing deck deterioration.

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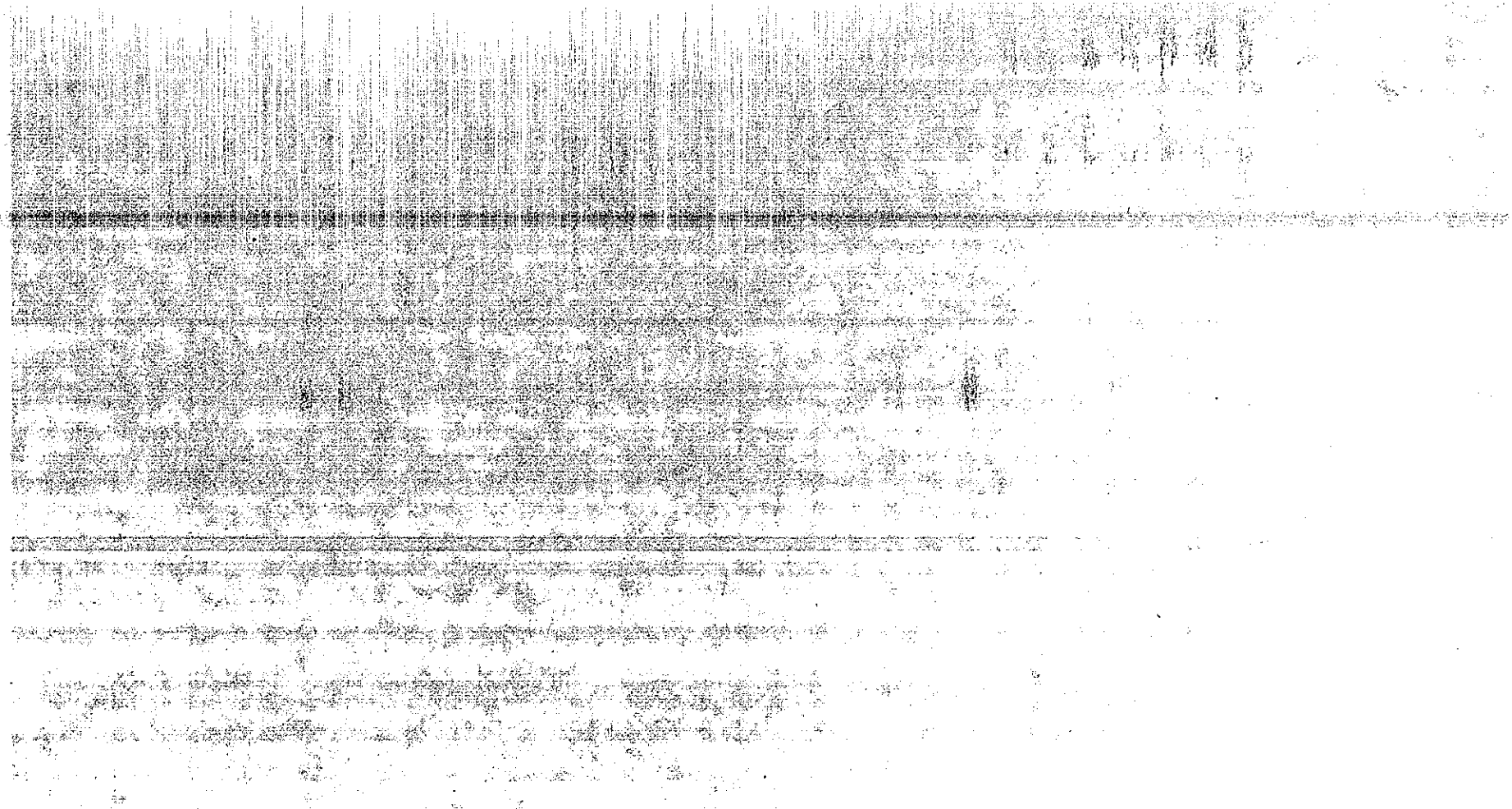

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SITE SELECTION AND PLANNING

The bridge selected for this polymer impregnation experiment is located on Route 395 in Nevada County, about 15 miles (24 km) north of Reno, Nevada, near the California-Nevada State Border. This location is at the 5,000 foot (1524 m) elevation in the Sierra Nevada Mountains and provides for a relatively severe environment. Wide daily temperature variations are common throughout the year resulting in approximately 100 freeze-thaw cycles annually.

The bridge is called Long Valley Undercrossing, Bridge No. 13-18 Lt. and carries southbound traffic. It is a single span conventionally reinforced concrete box girder structure. Total depth of structure is 4 foot-3 inches (1.3 m) and includes a 8-1/8 inch (206 mm) thick top deck (see Figures 1 and 2). The length is 70 feet (21.3 m) and width between curbs is slightly under 39 feet (12 m), or approximately 3,000 square feet (279 m^2) of area. Alignment is a 5,000 foot (1524 M) radius curve with a 0.25% grade and a 2% cross slope.

Initial plans were discussed with State personnel from the project as well as Contractor representatives. Full communication was necessary between all parties in order that the work could be conducted as efficiently and safely as possible and with a minimum of inconvenience to other road-building activities that were underway. For various reasons initial plans for some facets of the work were changed, and difficulties were encountered in obtaining some of the materials and equipment.

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It was originally planned to treat the entire bridge deck in a single operation. However, as time progressed it appeared that a situation could exist which would require a portion of the bridge deck to remain open in order to accommodate construction traffic. It was thus decided to impregnate the deck in two operations. The bridge deck was divided into two sections longitudinally, one section consisting of 1/3 of the deck and the other section 2/3 of the deck. The entire polymer impregnation process was completed on the first section before work began on the second section.

Our early experience with the polymerization process had involved the construction of four-inch (100 mm) high "dams" (made with 2 x 4's) (50 x 100 mm) on the deck surface, sealed to the deck to retain water. Small portable "boilers" were used to heat the ponded water in order that polymerization temperatures of 165°F (74°C) could be reached in the concrete. It was initially planned to use the hot water system on the Long Valley Undercrossing. The proposed system of applying large quantities of hot water to the deck, and recycling the water through a large boiler was investigated. The water being circulated would be continuously heated until the desired concrete temperatures were attained. It was decided to abandon this approach because of expected difficulties and high costs that would be involved in the construction of water-tight "dams" obtaining the initial supply of hot water, and construction of the recycling system. An alternate system was devised, to use a steam generator of adequate capacity, and entrap the steam under a cover to be constructed over each section to be polymerized.

Plans for obtaining a significant amount of help from the Contractor's force did not materialize. During the period in

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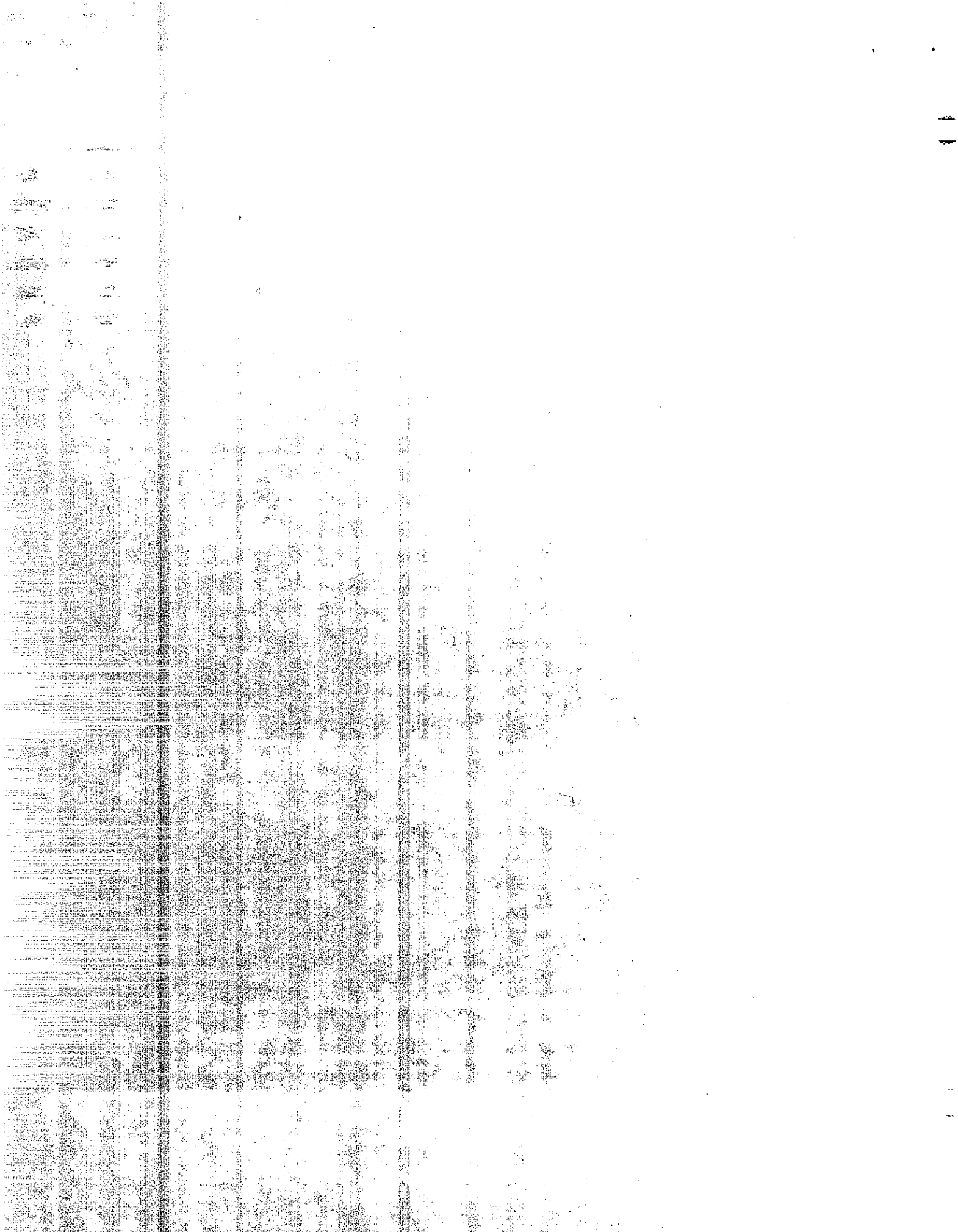

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which the deck treatment was underway the sub-contractor doing the bridge work had a skeleton crew of 2 or 3 people. Since the site is somewhat remote to population centers, obtaining tradesmen on short notice is difficult. As a consequence the most reasonable alternative appeared to be that of using personnel from the Transportation Laboratory in Sacramento for essentially all of the field work.

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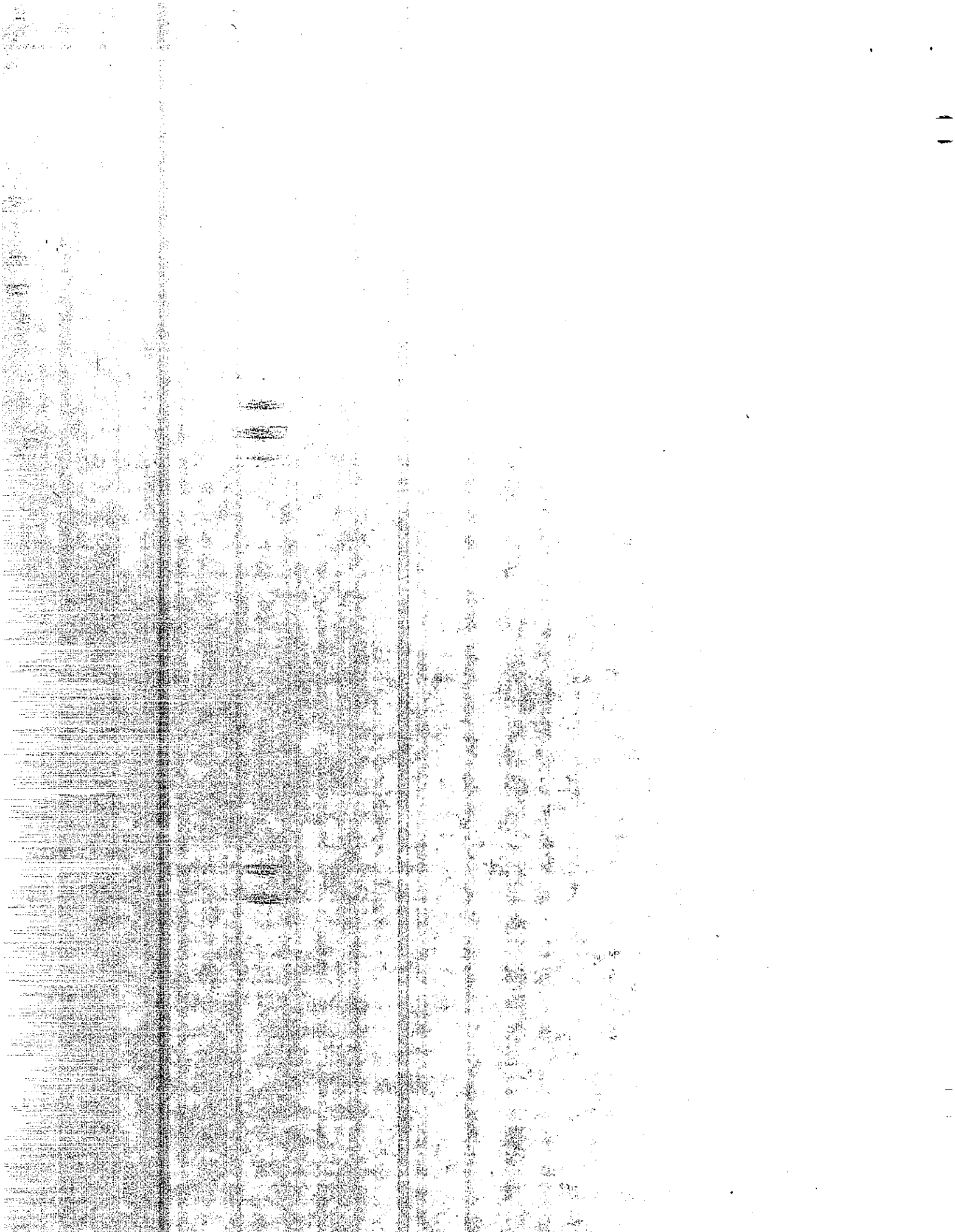

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POLYMERIZATION PROCEDURE

Instrumentation

Prior to placing deck concrete a total of 40 Type-J thermocouples were installed at various locations to be used to monitor the deck temperature both during the drying and steaming processes. Twenty-five of these thermocouples were located at a depth of approximately 2-3/8 inches (60 mm) by attaching them to the side of the #6 (19 mm) transverse top mat reinforcing steel. The remaining fifteen were located approximately 3/4 inch (19 mm) below the surface by securing them within a 2 inch x 2 inch x 2 inch (50 mm x 50 mm x 50 mm) concrete block. These blocks were attached to the longitudinal top reinforcing steel as shown in figure 3.

Drying

The first step in the impregnation process was to dry the deck surface to a depth of at least 1-1/2 inches (38 mm). The deck had been placed 28 days earlier and had received a moist cure for the initial 10 days following placement (See Fig. 4). After this 10 day cure period, the deck was allowed to air dry. Weather conditions were ideal for drying during this 18 day period following the removal of the moist cure, with temperatures in the 80's (30°C approximately), low humidity, and winds up to 25 mph (40 km/hr) on many days.

One-third of the deck on the lower crosslope was the first section to be dried. The remaining 2/3 portion of the deck area was not dried until the impregnation process had been completed on this first section. A large gas fired infrared

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heater supplied through a rental agreement with the Thermatronics Corp. of New Jersey, was used. The heater had a designed output of approximately 500,000 BTU's/Hr (146 kW). Fuel consumption (propane) was at the rate of 5-6 gallons/hr (5-6 ml/s).

Dimensions of the heater were 14 feet-6 inches wide (4.4 m), 5 feet-6 inches long (1.7 m), and 3 feet-0 inches (0.9 m) high (see Figures 5 and 6). Heat was supplied through a series of infrared heating elements located along each side of the heater. Two 20 gal (76 l) propane tanks were attached to the outside of the heater and supplied the required fuel. The frame of the heater was equipped with "V"-grooved wheel casters designed to ride on a metal track. Number 6 (19 mm) rebars available on the project provided an adequate track, and movement of the heater had to be accomplished by hand pushing (See Figure 7).

Prior to the actual drying of the first portion of the deck, a 1/4 inch (6 mm) thick layer of sand, which would be required during the monomer application, was placed on the deck. During the deck drying process, this layer of sand was also dried.

In order to prevent the overheating of the concrete surface, the initial heating process involved a certain amount of experimentation. Initially, heat was applied to one 14 foot-6 inch (4.4 m) x 5 foot-6 inches (1.7 m) area of the deck for 10 minutes, then the heater was moved ahead 5 feet (1.5 m) to a second area for 10 minutes, and then forward to a third area. Upon completion of the third section, the heater was returned to the first area and the procedure repeated. This forward and back procedure continued until the desired

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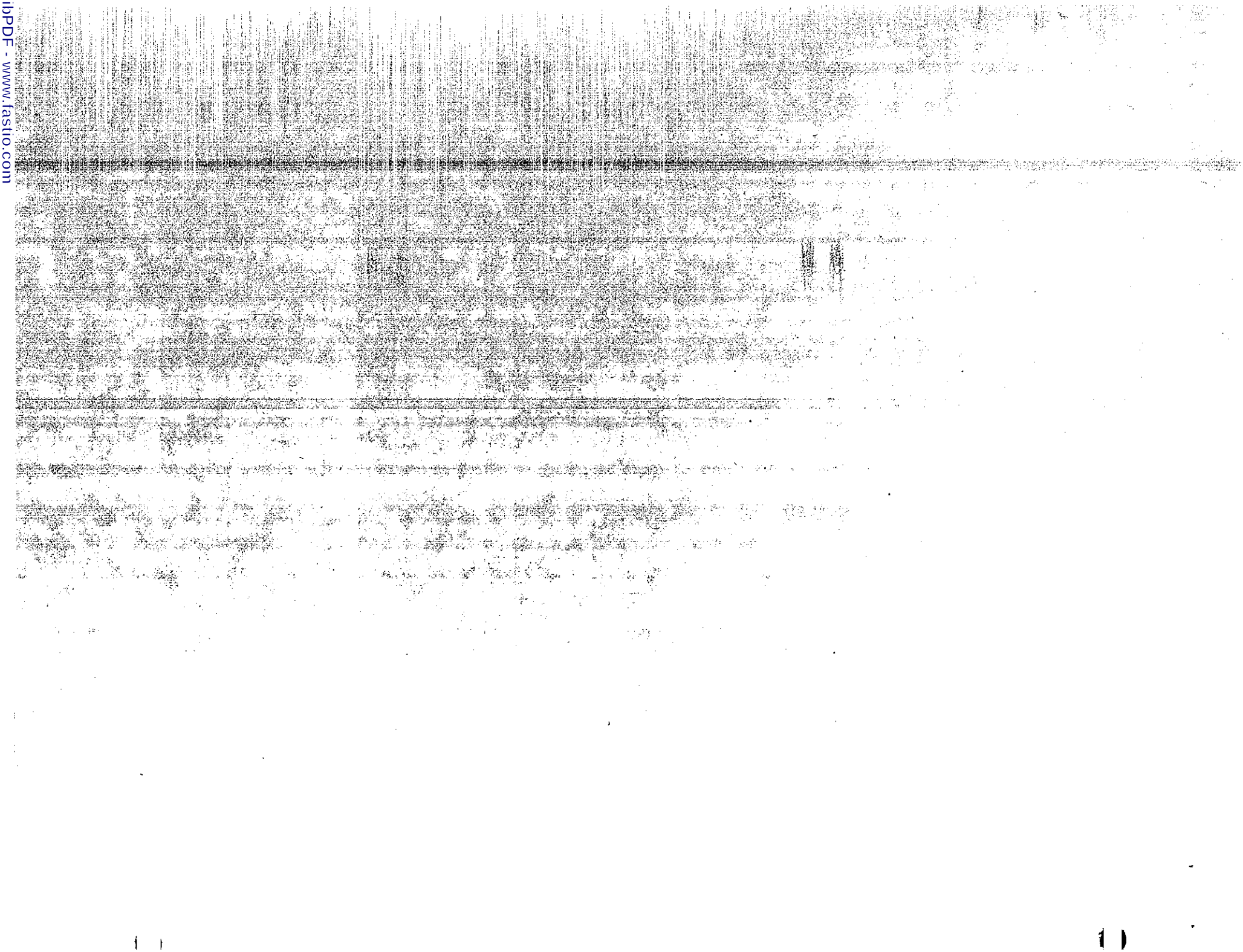

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temperature was achieved. The goal was to heat the deck to a minimum of 200° F (93°C) at a depth of 2 inches (50 mm) and to maintain this condition for about 1 hour.

Monitoring of the thermocouples indicated a considerable loss of heat from the time the heater was removed from one section until its return. This may have been due in part to the severe wind conditions. Surface temperatures of the deck as measured with a remote sensing device based on infrared radiation were in the 350° F (177°C) range immediately after the heater moved off an area, but dropped rapidly thereafter.

After monitoring the temperatures of these initial sections for some time, the heating procedure was changed slightly. The new procedure included the heating of two 14 foot-6 inch (4.4 m) x 5 foot-6 inch (1.7 m) areas alternately for approximately 20-25 minutes each. Then the process was repeated for an additional 20-25 minutes. This resulted in a total heating of nearly 50 minutes per 14 foot-6 inch (4.4 m) x 5 foot-6 inch (1.7 m) section. An insulating cover was placed on the surface after the first application of heat. In general, this procedure was followed for the rest of the deck. The typical temperature rise during the drying phase is shown in Figure 8. From visual inspection of the deck, no evidence could be found of any surface cracking as a result of the heating process.

The infrared heater was a prototype model that had very little usage prior to this project. Problems were encountered during the initial two days of drying which resulted in a considerable loss of time. After several attempts to repair a faulty valve the company representative decided to order a replacement.

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The new part was installed and additional adjustments were made. Even after these adjustments, there still appeared to be some problem with the regulation of fuel to the heating elements. One bank of elements appeared to burn much brighter than the other. This condition was not fully corrected and may possibly have had some effect on the rate of heating during the drying process.

The drying process used on the second section (upper 2/3 of the deck) was the same as that used on the first section except that the layer of sand was not first placed on the deck. Instead, the sand was spread out on the dried portion of the deck and allowed to air dry.

Drying of the second section continued until rain was encountered near the end of the final day of drying. As rainfall threatened, the deck was covered with two layers of polyethylene sheet. Upon removal of the plastic sheeting it was discovered that some rain had leaked through, wetting portions of the deck. As a result the entire section had to be redried. This was accomplished the following week.

The entire drying process was considerably slower than had been expected. Part of this was due to the heavy winds encountered during drying, and in addition, it was felt that the heater was not operating at peak efficiency.

Portions of the deck that had been dried were covered with polyethylene sheeting to prevent condensate from entering the concrete. After drying, the concrete was allowed to cool until the following evening. The 1/4 inch (6 mm) layer of sand was then spread on the deck and the surface was ready for monomer application.

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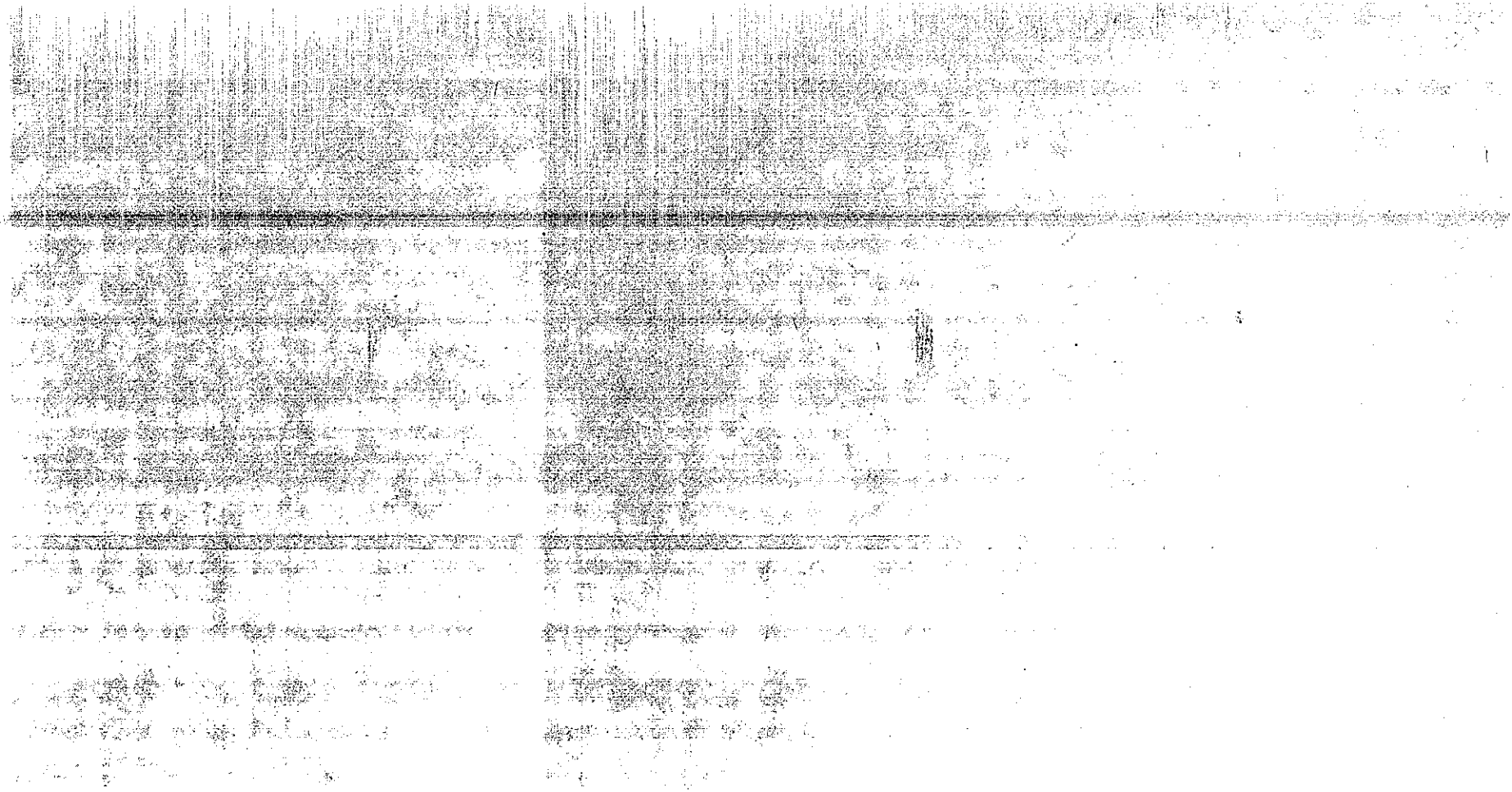

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Monomer System

The monomer system selected for use on this project was the same one used for the impregnation of the test section near Sacramento in 1974(6). It consisted of 90% by weight of methyl methacrylate (MMA) and 10% of weight of trimethyl-olpropane trimethacrylate (TMPTMA) which is the crosslinking agent. To this basic 90-10 mixture was added 2% of 2, 2' azo-bis-isobutyronitrile (A-BN) as the free catalyst.

The MMA, TMPTMA, and A-BN were all transported to the jobsite and stored in separate containers until just prior to use. The mixing procedure involved the removing of 10% MMA from its 55 gal (208 l) containers and replacing it with 10% TMPTMA. Once the required amount had been mixed for all the 55 gal (208 l) containers, the catalyst (A-BN) was added to each container. This involved first pumping approximately 2/3 of the contents of the 90-10 solution out of its 55 gal (208 l) drum and into an open 55 gal (208 l) container. The required amount of A-BN was then added slowly and mixed by stirring for several minutes.

Once the catalyst had completely disolved, the combination of MMA, TMPTMA, and A-BN was pumped back into the original 55 gal (208 l) drum and sealed. This procedure was followed for each drum.

After mixing, which was done shortly before application, the mixed monomer system was placed on a truck and transported to the bridge site approximately one mile (1.6 km) away.

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Application of the monomer system to the layer of sand began at approximately sundown. The procedure involved attaching a 50 foot (15 m) rubber garden hose to the outlet of the 55 gal (208 l) drum, laying the drum on its side, and allowing the monomer to flow by gravity from the 4 foot (1.2 m) high truck bed to the outlet of the hose, which was equipped with a garden type fan sprinkler head.

Application was accomplished by passing the sprinkler back and forth over the deck area by hand until the sand was uniformly saturated (see Figures 9 and 10). The required area to be covered by each 55 gal (208 l) drum was pre-determined and used as a guide during the application. Approximately 0.7 pound (2.3 kg/m^2) of monomer per square foot of deck area was applied during the initial application. Two additional lighter applications were made during the evening in order to maintain a saturated sand condition. A total application of approximately 1.1 pound of monomer per square foot (5.4 kg/m^2) was eventually achieved.

Six mil (.15 mm) thick sheets of polyethylene were used to cover sections of the deck to prevent evaporation following each application of the monomer (see Figure 10). After the final application, the monomer was allowed to soak until early morning (approximately 10 hours).

Beginning at approximately 0700 hours, the layer of sand was removed from the surface of the deck (Figure 11). One section at a time, (approximately 36 feet by 8 feet (11 m x 2 m)) was uncovered, broomed clean of the sand, and then immediately recovered with the polyethylene sheeting.

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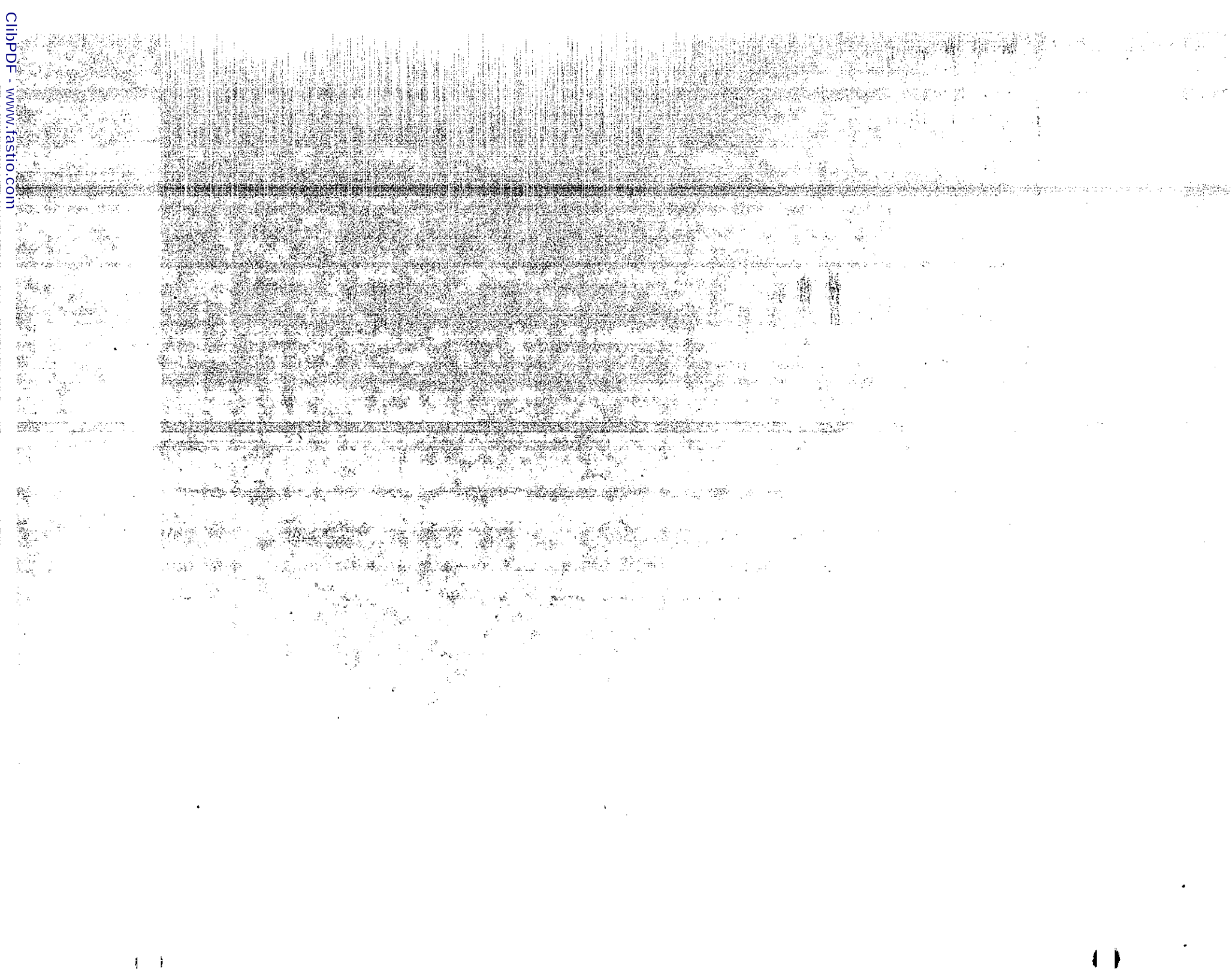

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Polymerization

Immediately after the sand removal, the steam piping system, which had been pre-fabricated to facilitate rapid installation, was assembled on top of the polyethylene deck covering. Once the piping system was in place, 36 feet x 8 feet x 6 inches (11 m x 2 m x .15 m) high forms which made up the enclosures for the steam chamber (see Figures 12 and 13) were lifted into place over each leg of the piping system. Just prior to placement of each enclosure section, the polythylene covering on the deck was removed. This left the piping system resting directly on the deck with the insulated-covering forming a 6 inch (152 mm) high closed chamber to retain the steam. The insulated steam hose from the steam generator was then attached to the piping system and the steaming cycle started.

The portable steam generator used during the polymerization process was supplied through a rental agreement with the Western Power Equipment Corporation of Redwood City, California Zsee Figure 14). Specifications included:

Electrical Power Required	240V-3 phase
Fuel Type	Diesel
Water Supply	200 Gal/Hr (210 ml/s) @ 30 psi (207 kPa)
Output	1,500,000 BTU's/Hr (440 kW)

Readings of the thermocouples were made to determine the temperature of the concrete during the polymerization process. The steam chamber temperature was also monitored. Steaming continued until all thermocouple readings indicated a minimum

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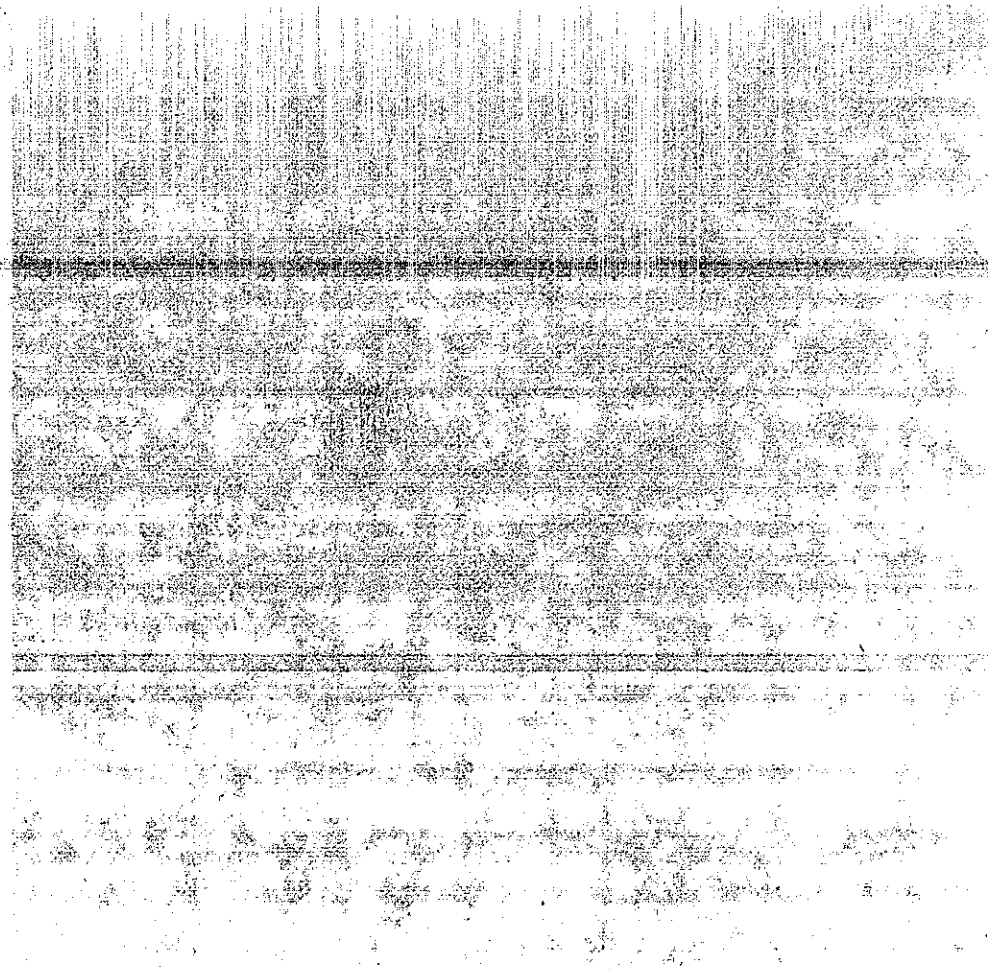

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of 165°F (74°C) at a depth of 2 inches (50 mm) and then maintained for an additional hour. Once this had been accomplished, the polymerization cycle was completed. Figure 15 shows typical temperatures during polymerization.

The portable steam generator appeared to do an excellent job of supplying an adequate amount of heat during the process. The total required time from start up of the generator to shutdown was approximately 6 hours.

System Evaluation

Eight 3 inch (75 mm) diameter cores were taken at random locations to aid in evaluating the effectiveness of the impregnation process. From visual observations the depth of penetration of the monomer was approximately 1/2 to 1 inch (13 to 25 mm).

Two of the cores cut from the deck were cut into horizontal slices and absorption determined for each slice. Results were as follows:

Core No.	Representing Concrete From	Percent Absorption
PIC #5	Surface to 1 inch (25 mm) deep	3.3
	1-1/8 inch to 2 inch (28 to 50 mm) deep	6.8
PIC #2	Surface to 3/4 inch (19 mm) deep	3.15
	7/8 inch to 1-7/8 inch (22 to 48 mm) deep	6.0
	2 inch to 3 inch (50 to 75 mm) deep	

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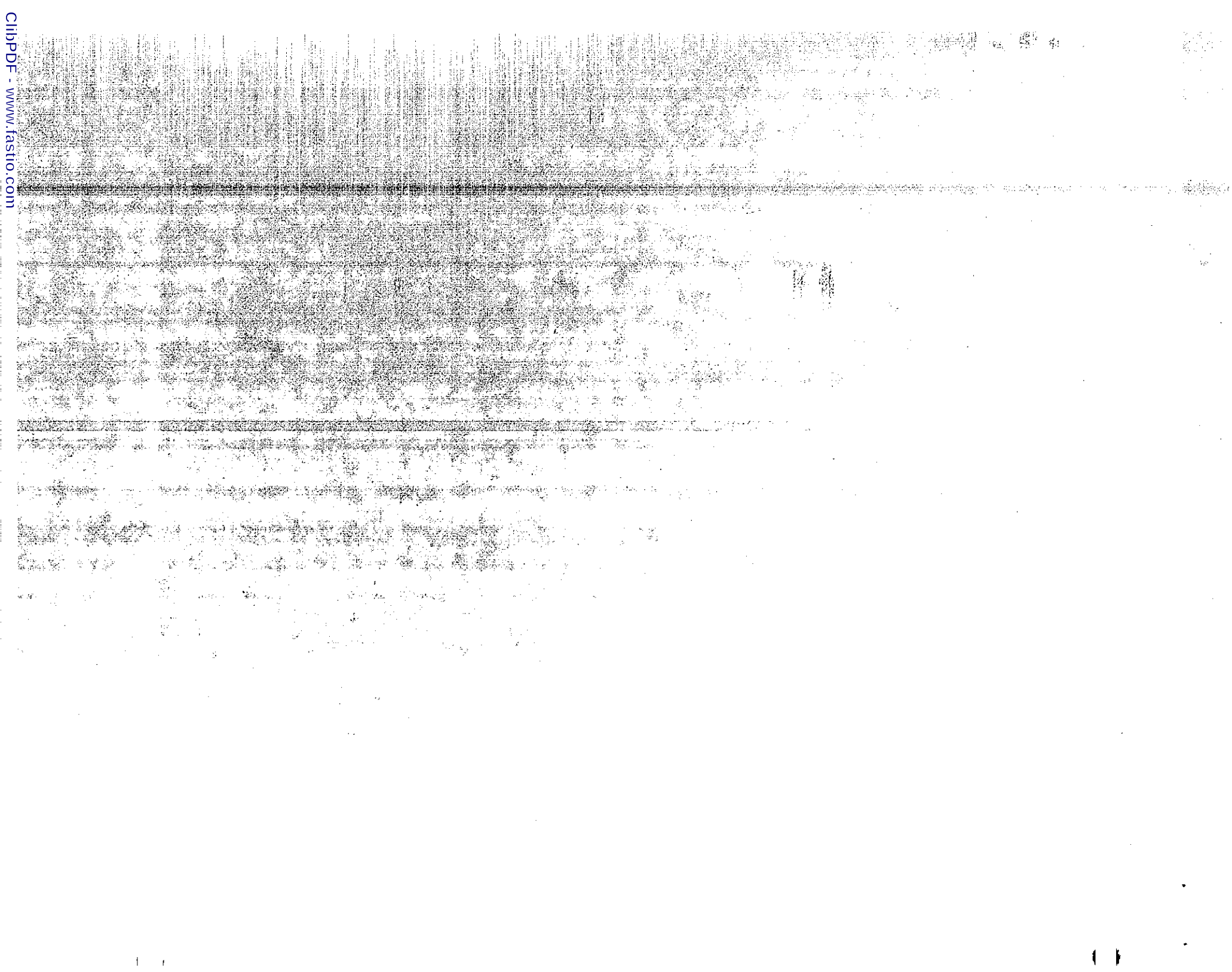

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Normally the top slice of a concrete core would have an absorption slightly greater than the underlying concrete. Since the absorption of the top 3/4 inch (19 mm) was only about one-half of the underlying concrete it appears that many of the voids were blocked or filled by the impregnation process.

Cut and polished faces of the cores were treated with tetrabromo-fluorescein sodium salt and uranium acetate and viewed under ultraviolet light. No great difference in the cut surfaces was evident. It was believed that if there were more exposed voids in the lower portion of the face, they would "hold" more of the light-sensitive material and the depth of the impregnation would be clearly visible. Some more positive method of determining monomer loading is needed to evaluate impregnation.

Resistivity Measurements

Electrical resistance tests were made using a high impedance Simpson ohmeter making connections between the deck surface and imbedded reinforcing steel. Wet sponges (about 1/2 square foot (.05 m^2 in area) were placed on the deck and curbs and resistance readings made at various time intervals. This is the same procedure for testing waterproof membranes.

The resistance measured depends upon the total absorption of the concrete, degree of saturation, and temperature. As the amount of water absorbed from the sponges increases, the resistance approaches some minimum value.

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Four curb measurements were made, two through an epoxy coating that was placed to protect the curb from salt action, and two others were made in an area where the epoxy coating was scraped away to expose the bare concrete. The other 26 test spots were located on the deck area that was impregnated with the monomer. One measurement was also made on the vertical face of the abutment wall. The results are shown in the following table:

	Time After Initial Wetting			
	3-5 min.	8-10 min.	15 min.	30 min.
	West Portion of Deck			
Resistance, ohms (Geometric mean) (Avg. of 15 points)	38.3 K	29.7 K	13.3 K	12.6 K
Coated Curb	12 K	17- K	18 K	29 K
Bare Curb	4.4 K	4.5 K	5 K	12 K
Side Wall of Abutment	20 K initial and 3.2 K 20 minutes later			

	3-5 min.	8-10 min.	17 min.
	East Portion of Deck		
Resistance, ohms (Avg. of 10 points)	11.7 K	11.5 K	11.8 K
Coated Curb	80 K	150 K	150 K
Bare Curb	3 K	3 K	2.8 K

Centerline of deck after 12 minutes was 10 K and after 19 minutes was 4.6 K.

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DISCUSSION

The impregnation process is a highly specialized operation requiring close inspection to achieve desired results. Normal inspection methods which depend upon visual observations and tests are, for the present time, of little value since the drying, impregnating, and polymerizing processes are occurring beneath the surface of the concrete. Monitoring of temperature by thermocouples provide the only quantitative data upon which conclusions regarding the adequacy of drying and polymerization are based. Even though an adequate initial level of drying is achieved, preservation of that state using the techniques described herein is questionable. The actual moisture condition of the concrete at the time of momomer application is an unknown. Once the concrete is dried some protective measures must be taken to prevent changes due to ambient atmospheric conditions. Little is known about the migration of moisture within a deck slab during the 24 plus hour period that elapsed between drying and monomer soaking, but limited experience indicates that there was no special problem.

Chemicals

Special skills are required in handling the polymerization chemicals and carrying out certain operations. The monomers have an obnoxious odor and concentrated or prolonged exposure may result in toxic effects or allergic reactions. Carbon cannister respirators were used by personnel exposed to the fumes. Protective shoes and clothing were worn to minimize the chance for direct skin contact.

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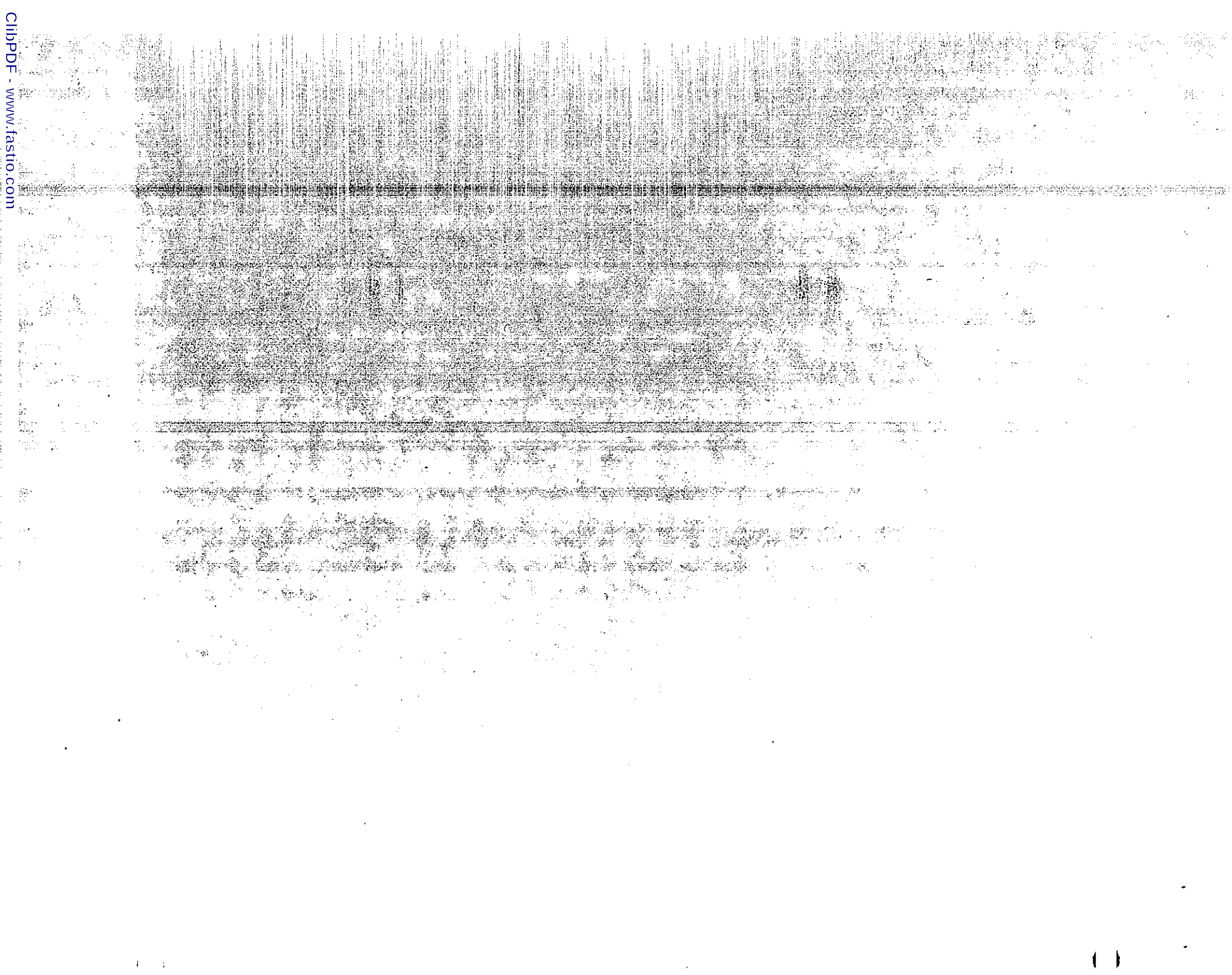

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In handling the catalyst, which is a fine white powder, care has to be taken to prevent contact with the skin or inhalation of the dust as the material is carcinogenic. Once the catalyst and monomers are mixed, care in storage must be exercised. Mixing should be done immediately before application and reasonable precautions should be taken to keep the mixture as cool as possible. Indoor storage of uncatalyzed materials in a ventilated building or outdoor storage in a shaded area is normally adequate. On this project the truck carrying 55 gallon (208 l) drums of the mixture was parked in the shade beneath the bridge between the time of mixing and application. After the catalyst has been added, storage time is very limited.

Heating Equipment

California's earlier experience with deck drying had been with the use of an infrared propane heater. The heating unit was cantilevered off the rear end of a small garden tractor and covered an area of about 5 feet by 8 feet (1.5 x 2.4 m). Attempts to obtain the same or a similar unit for use on the Long Valley structure were unsuccessful. At the time arrangements were being made for equipment to do the work, it was learned that a prototype model heater, known as the LARH Bridge Heater had been developed by a private concern in New Jersey. A service agreement was negotiated to obtain this device. It had a greater areal capacity than the unit previously used, 5 feet x 14 feet (1.5 m x 4.3 m), but like many prototypes, certain operating aspects had to be corrected on the jobsite before it was functioning adequately. It proved to be somewhat difficult to move about on the bridge deck because of the weight (it is not self propelled) and small (6 inch) (150 mm) diameter steel wheels. Two of the four wheels were

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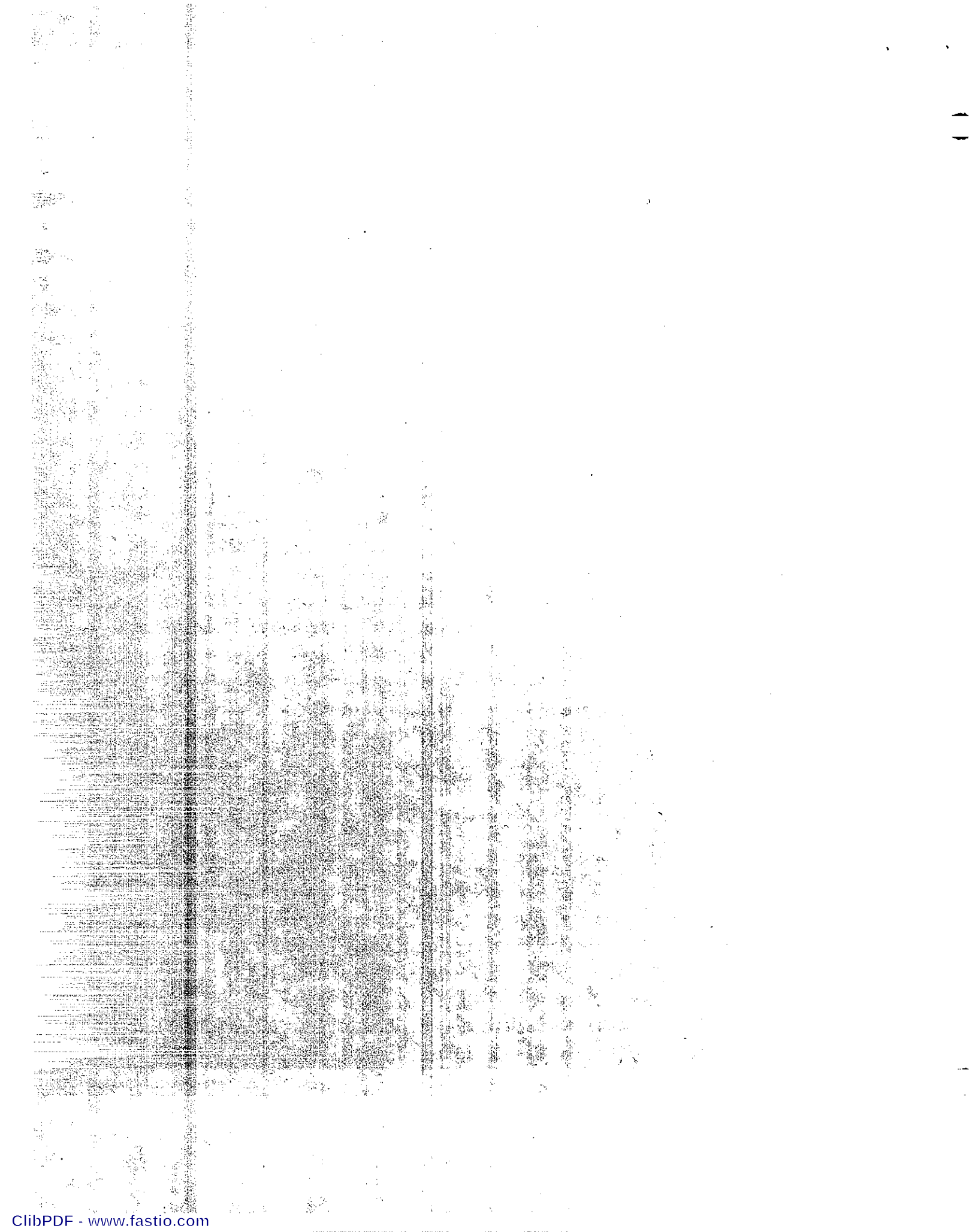

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castered, however, the castered wheels were not free to swing a full 360°. When the castered wheels were leading in the direction of movement there was no particular problem. Reverse movement resulted in the casters swinging only part way and binding against the interior of the framework. Once the heater was lined up on the deck, the V-slot in the wheels rode satisfactorily on No. 6 (19 mm) reinforcing bars used as rails. A power propulsion unit and selfsteering would be an improvement for future application of the LARH heater.

Steam Generator

The portable steam generator proved to be a very effective piece of equipment for providing polymerization heat. The operator used at the site had extensive experience as a building maintenance engineer and no difficulties in operation were encountered. With a brief training period others could quickly learn the basic operating procedures. However, should problems arise or troubleshooting be necessary an experienced person should be on hand.

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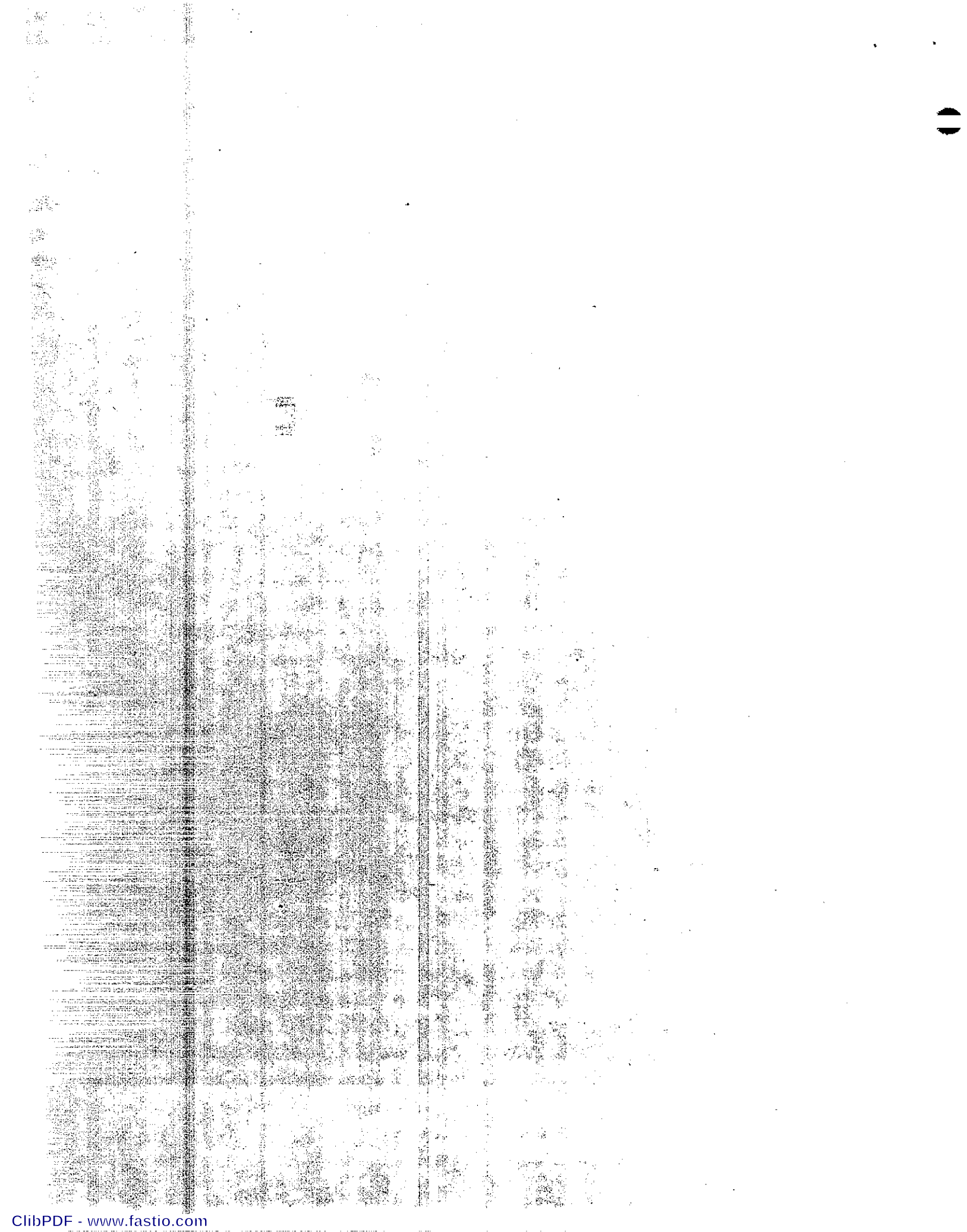

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DISCUSSION OF ELECTRICAL RESISTANCE MEASUREMENTS

Because of the geometric distribution, the resistivity measurements should not be compared by simple averages, but rather the geometric means. On the westside of the deck the resistance decreased with time over a period of about 15 minutes (see Table). On the east portion, the initial readings were essentially the same as the readings at later times. The initial resistance of the concrete on the west portion was higher than that of the east side which indicated that the west portion was drier to start with, but based on final measurements it is concluded that the polymer content on each part was about the same.

To judge the relative effectiveness of the polymer impregnation in inhibiting salt water penetration we can compare the deck surface readings with those on the curbs. The deck concrete resistance was about three times greater than the bare, untreated concrete on the curbs. By referring to Figure 7 in a report by R. F. Stratfull titled "How Chloride Affect Concrete Used With Reinforcing Steel" Materials Protection Vol. 7, March 1968, it is seen that a three fold increase in electrical resistance is an indicator that the water contained by the concrete is decreased about 50%. It can therefore be concluded that the impregnation process has reduced the concrete absorption by about 50%. A reduction in absorption of this magnitude is expected to double the time to corrosion if salts are applied. This relationship, however, might not be true for the epoxy coated concrete as once the salt water goes through any break in the film, it would be free to travel through the plain concrete at a higher rate.

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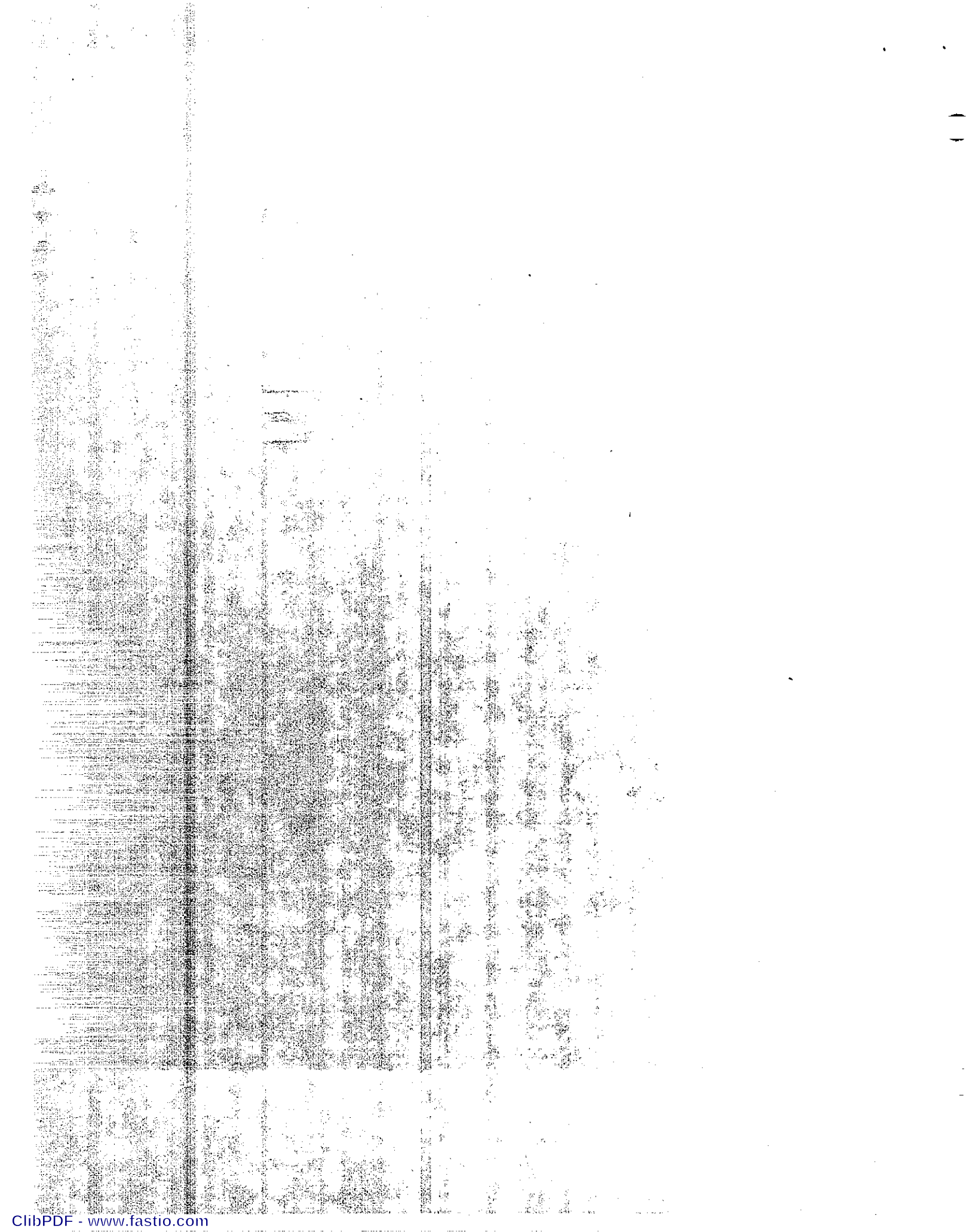

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While resistance measurements do show a difference in the resistivity of the impregnated concrete and the plain concrete, the significance of the measurements relative to performance of monomer impregnated deck concrete is not known. Resistance of waterproof membranes would not be comparable. It is likely that even if the voids were 100% filled with monomer and water transmission were nearly zero, we would still be able to obtain fairly low resistance readings through the concrete matrix. For this reason resistivity is probably an ineffective measure of penetration of the monomer or the permeability of the concrete.

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COST ANALYSIS

It is difficult to prepare a meaningful cost analysis of the impregnation process. Actual unit costs for doing the work on this particular project are considerably inflated because:

1. Since the project was the first "full-scale" application of its type for all personnel, a certain amount of inefficiency is to be expected.

2. The remoteness of the site from the control laboratory increased costs of travel and transporting equipment and supplies significantly.

3. No re-use of most of the special items constructed for or used on this one project. Since there is virtually no competition for the special equipment such as the dryer and steam generator, rental costs are high.

4. The size of the deck receiving the treatment was relatively small, tending to increase unit costs.

A "best estimate" of costs (at current prices) to polymerize a new deck of 3000 square feet (28 m^2) assuming that the above deficiencies can be overcome, is as follows:

Instrumentation

Thermocouple wires ($0.10 ft (0.3 m) x 200 ft (610 m))	$ 200.00
Fabrication & Installation (24 hrs x $20/hr)	480.00

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Drying of Deck

Infrared heater (rental)	$ 800.00
Operation & monitoring (60 hrs x $20/hr)	1,200.00

Impregnation

Monomer system materials	2,700.00
Dry sand	200.00
Mixing and application (60 hrs x $20/hr)	1,200.00

Polymerization

Steam Generator (rental)	1,000.00
Electrical Generator & Water Storage Facility Rental	100.00
Piping System (Based on Reuse)	200.00
Steam Chamber (Based on Reuse)	300.00
Installation & Operation (80 hrs x $20/hr)	1,600.00
Cleanup, etc. (24 hrs x $20/hr)	480.00

Miscellaneous Equipment

Safety Equipment, Monitoring Equipment, Lighting, etc.	800.00
Total	$11,260.00
Estimated Cost per Square Foot $\frac{\$11,260}{3000\ (28\ m^2)}$	$ 3.75
Approx.	$ 400/m^2

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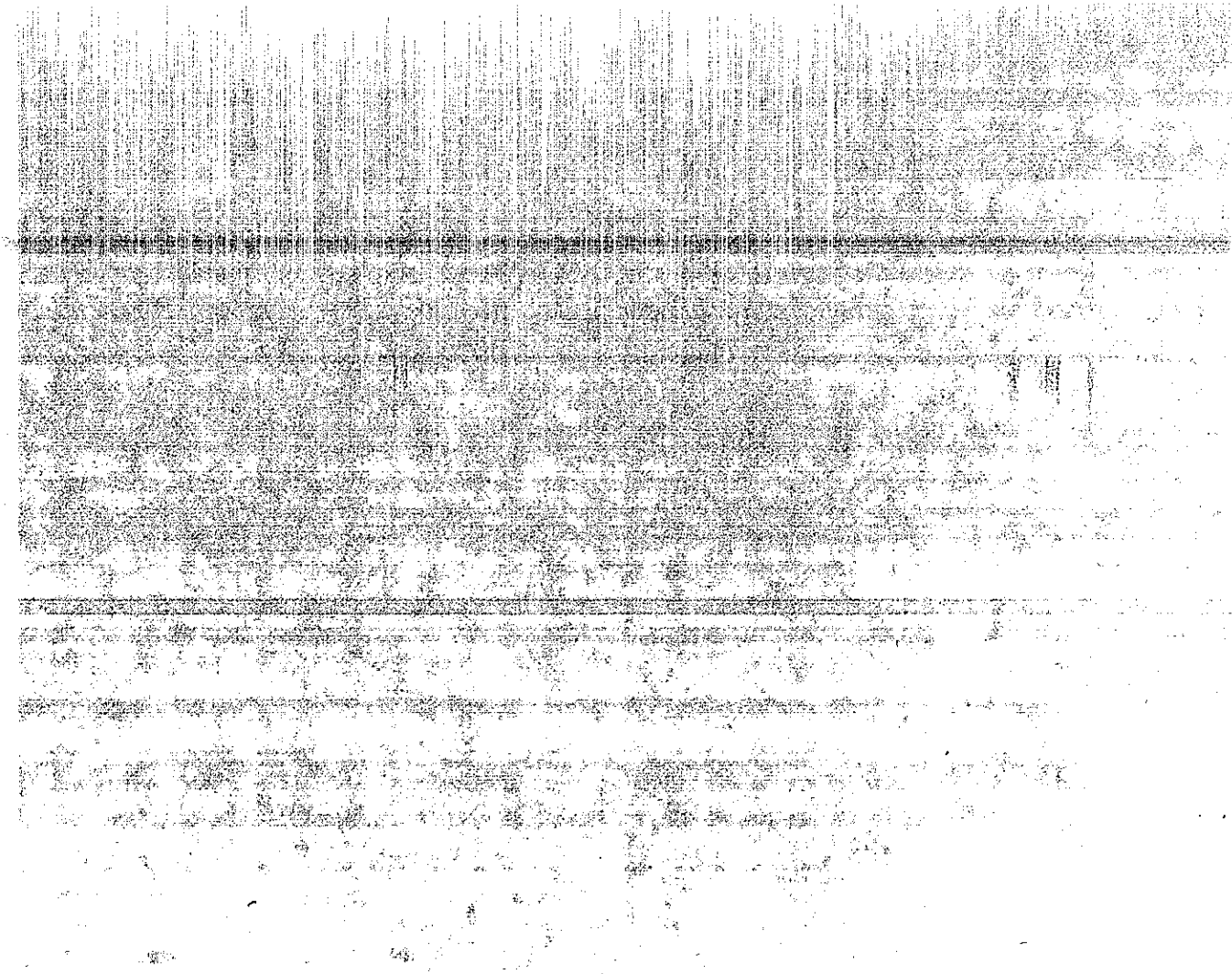

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CONCLUSIONS

Impregnation and polymerization to a depth of one-half to one inch (12.5 to 25 mm) was achieved.

The complexities of the process, including the care required in handling chemicals, the need for and lack of specialized equipment and the critical aspects of drying the deck, and later, for polymerization are such that it is beyond the scope of the typical highway contractor. Proper inspection is also beyond the scope of typical field forces. Specialty contractors, prequalified for this type of work and trained field inspectors are believed to be necessary for successful application.

Critical operations are conducted under the assumption that certain results will be achieved. Heat is applied in order to dry the concrete to some desired depth, the "dried" concrete state must be preserved until monomer is applied, monomer saturation is maintained until the desired penetration is achieved, and adequate heat is then applied for polymerization, all of which takes place out of sight, beneath the surface of the concrete. Before uniform successful implementation of the polymer impregnation process could be expected in actual practice, techniques and procedures must be developed for assuring that each of the critical operations are satisfactorily carried out.

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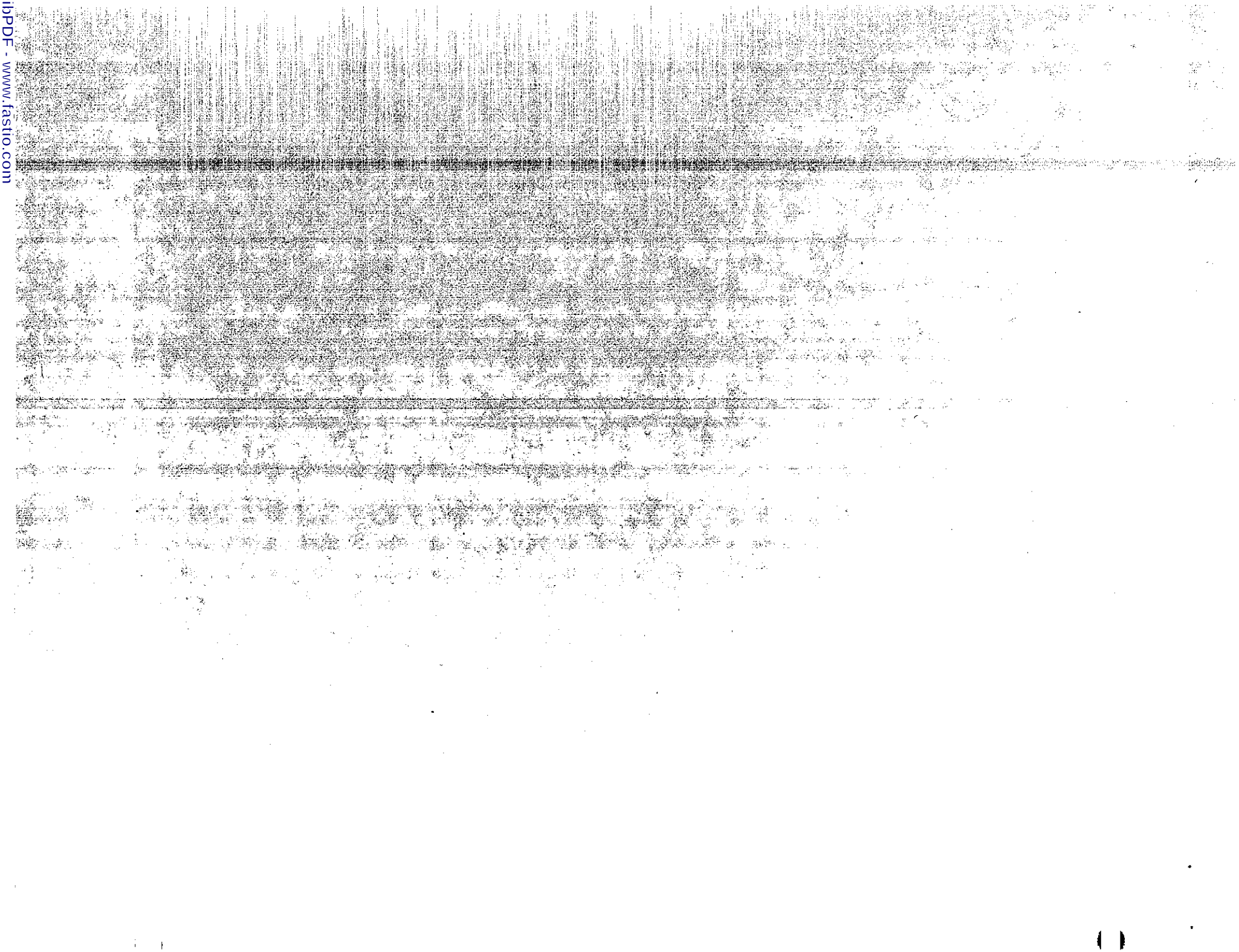

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FIGURES

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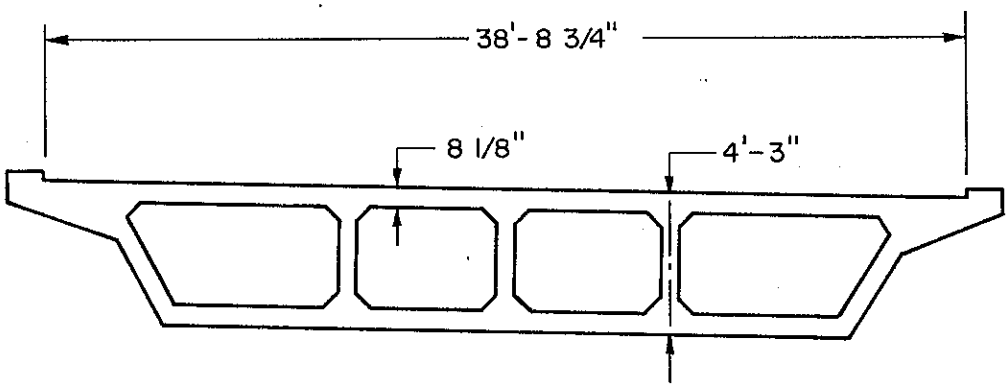

Figure 1 - Cross Section of Long Valley Undercrossing

Note: 1 inch = 25.4 mm

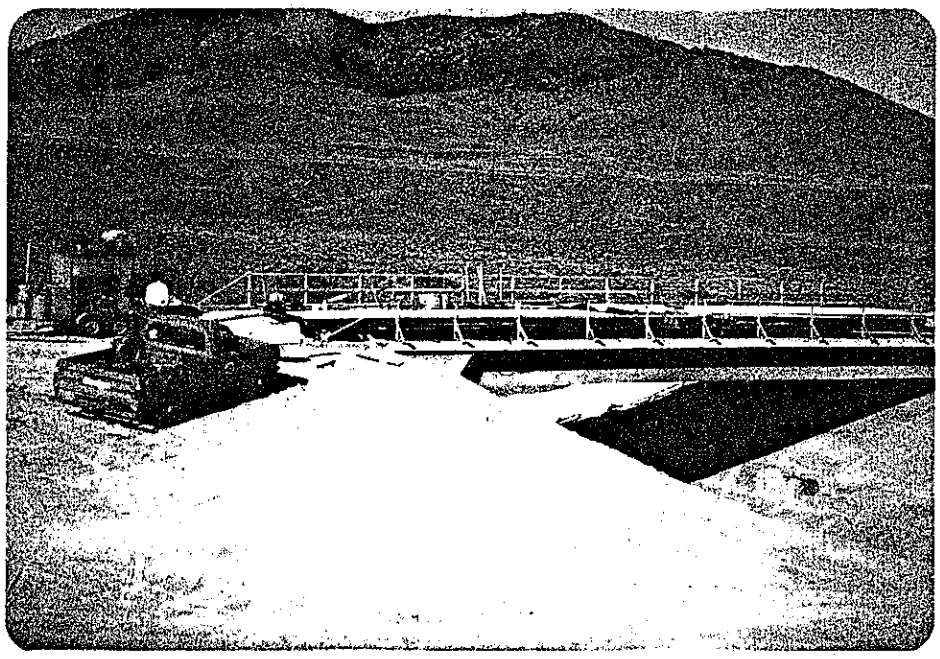

Figure 2 - General View of Long Valley Undercrossing

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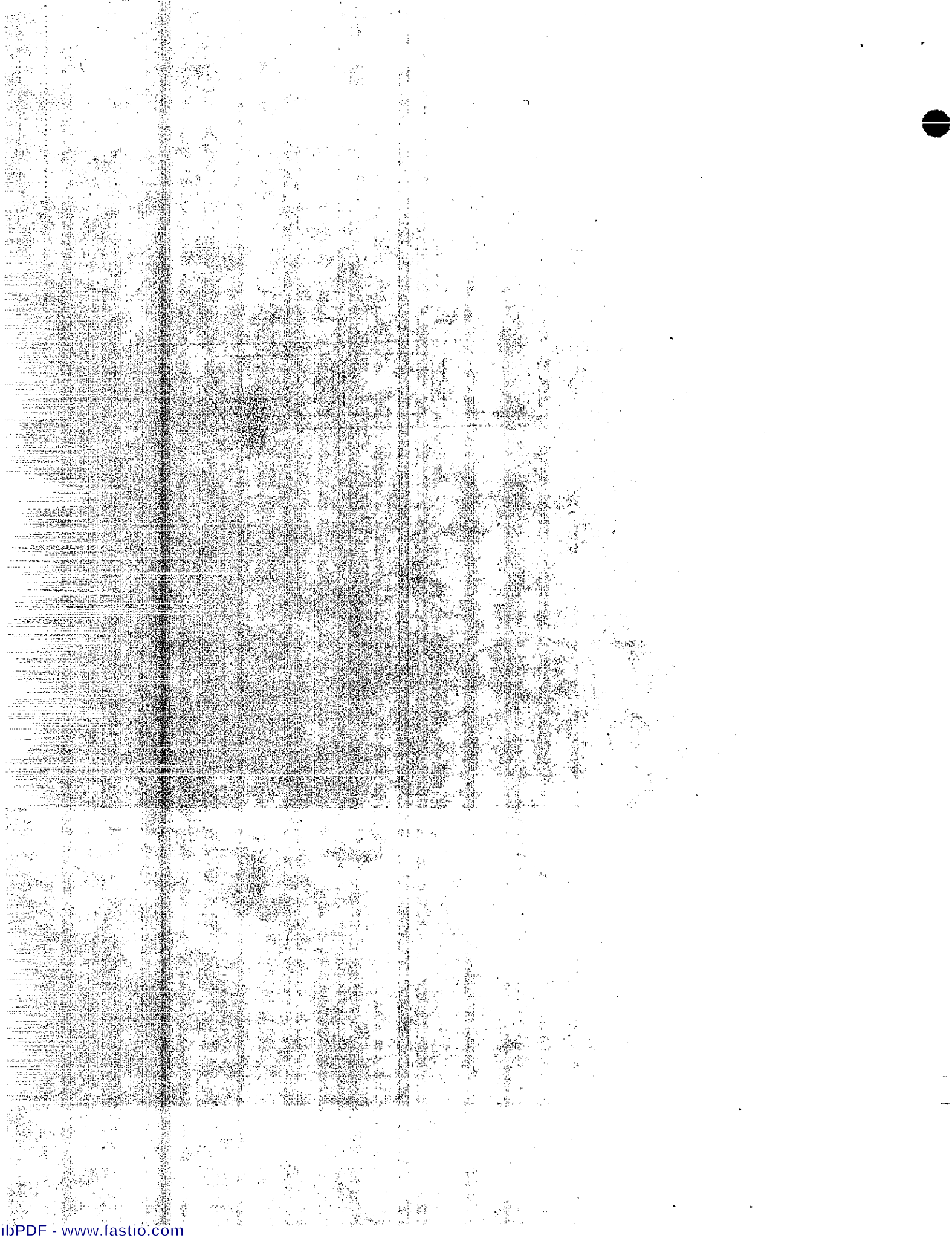

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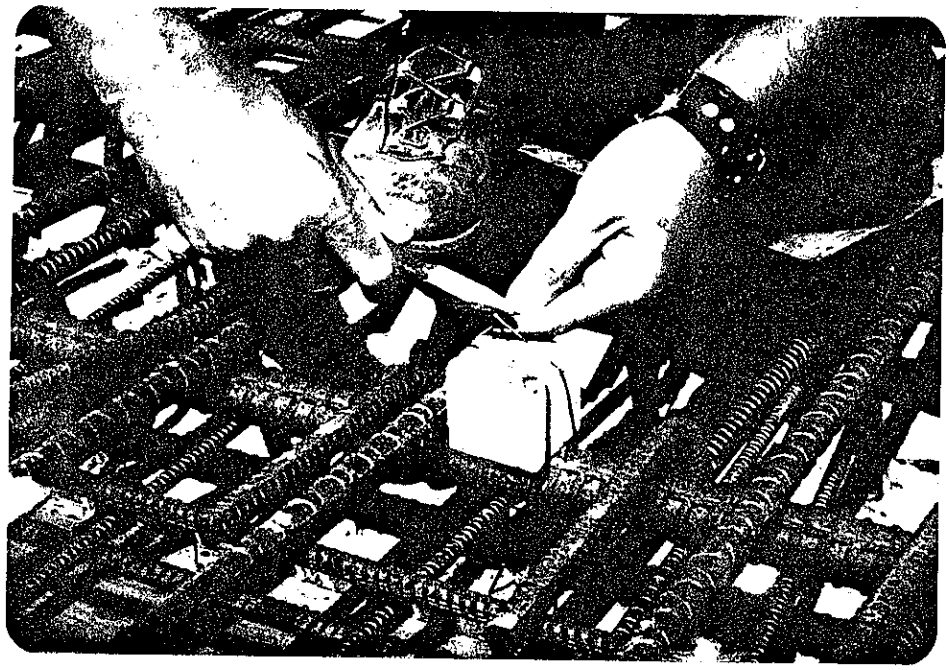

Figure 3 - Installation of 2 inch Concrete Cube Containing Thermocouple

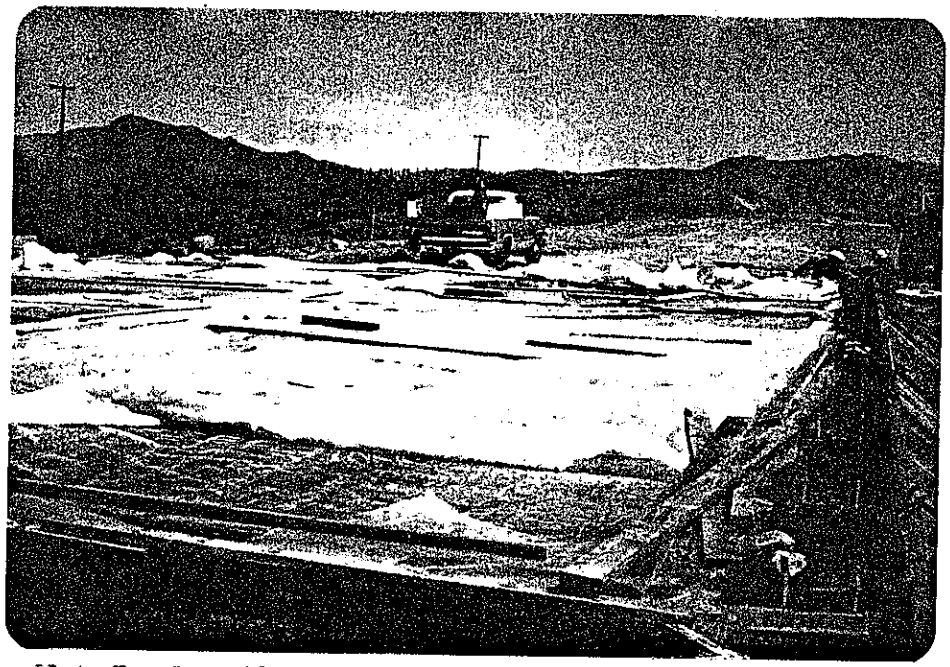

Figure 4 - Wet Burlap With Polyethylene Cover Used For Curing of Bridge Deck Concrete

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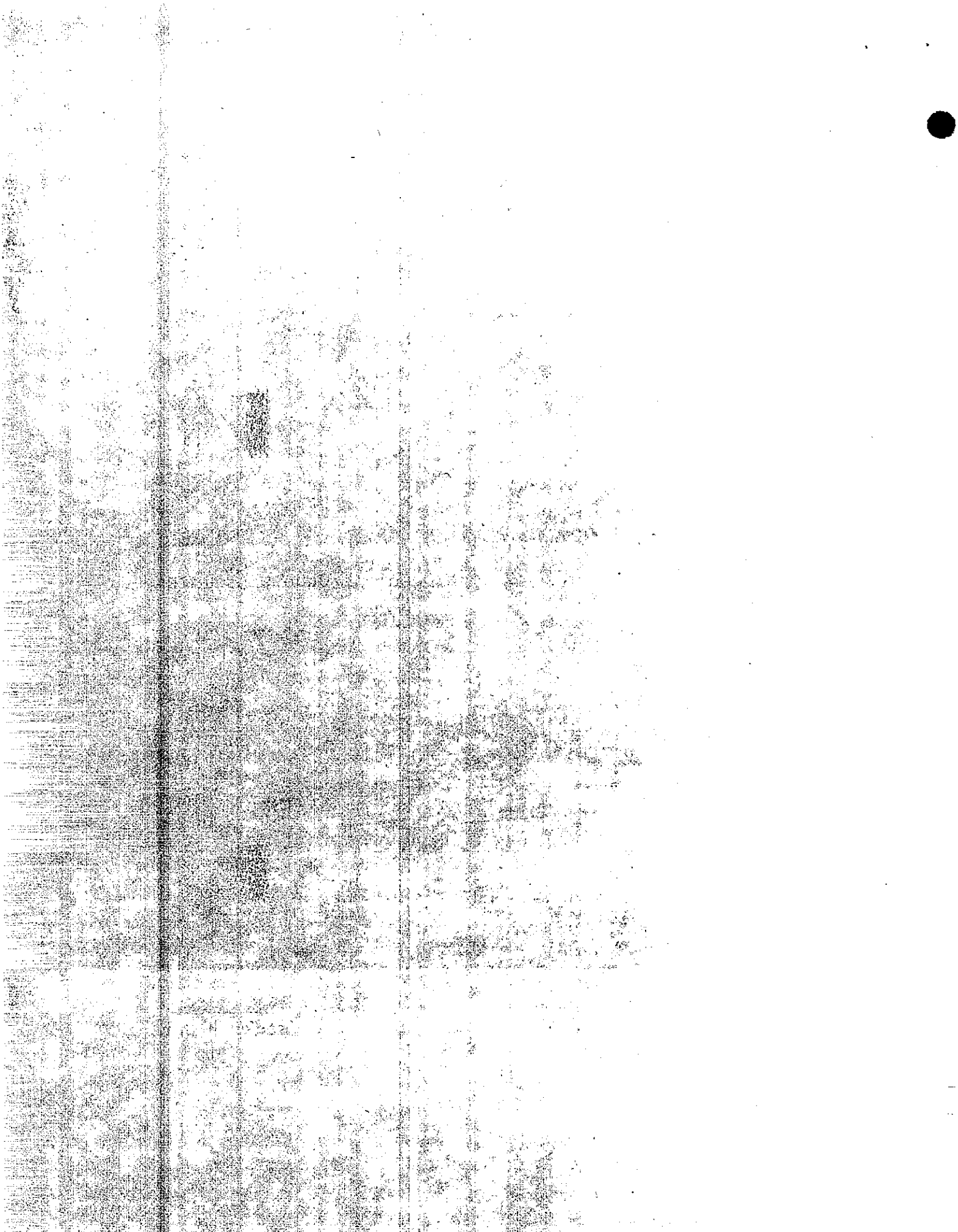

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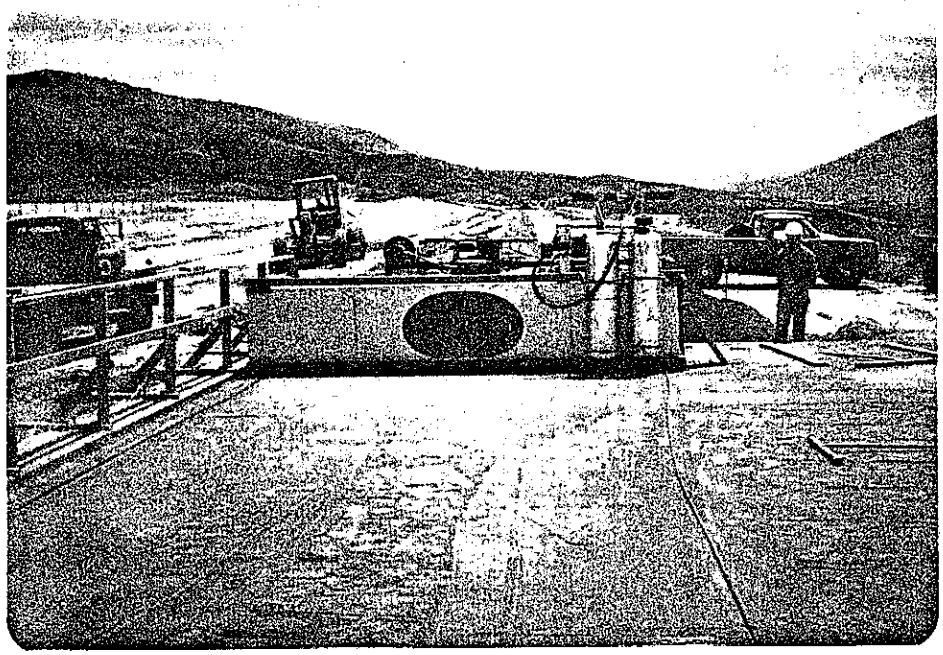

Figure 5 - Infrared Heater Used in Drying of Deck, Quarter Inch Sand Layer In Place and #6 Rebars Laid Out For Track.

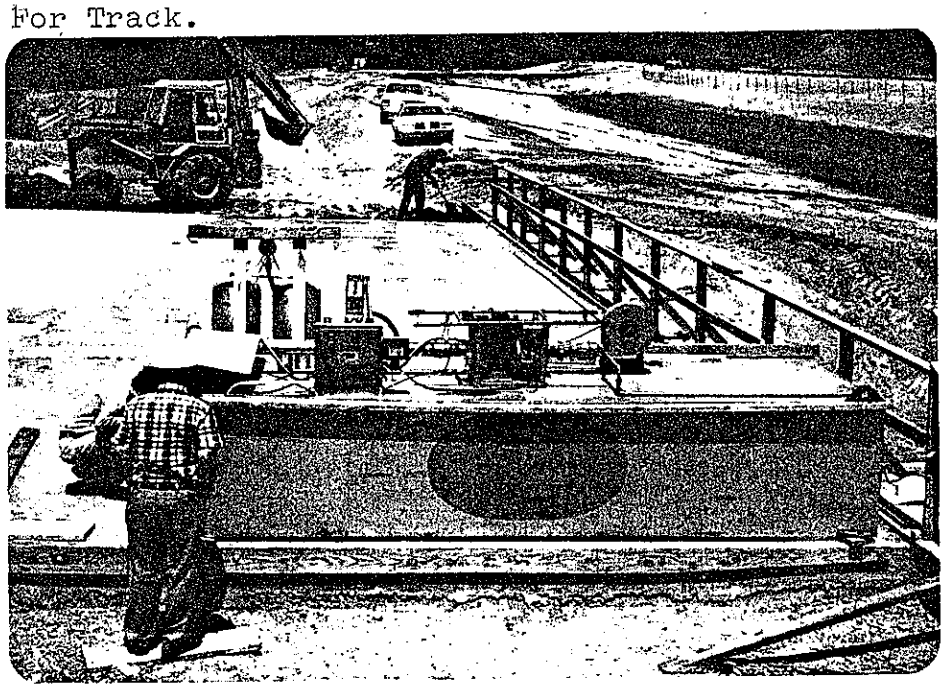

Figure 6 - Infrared Heater

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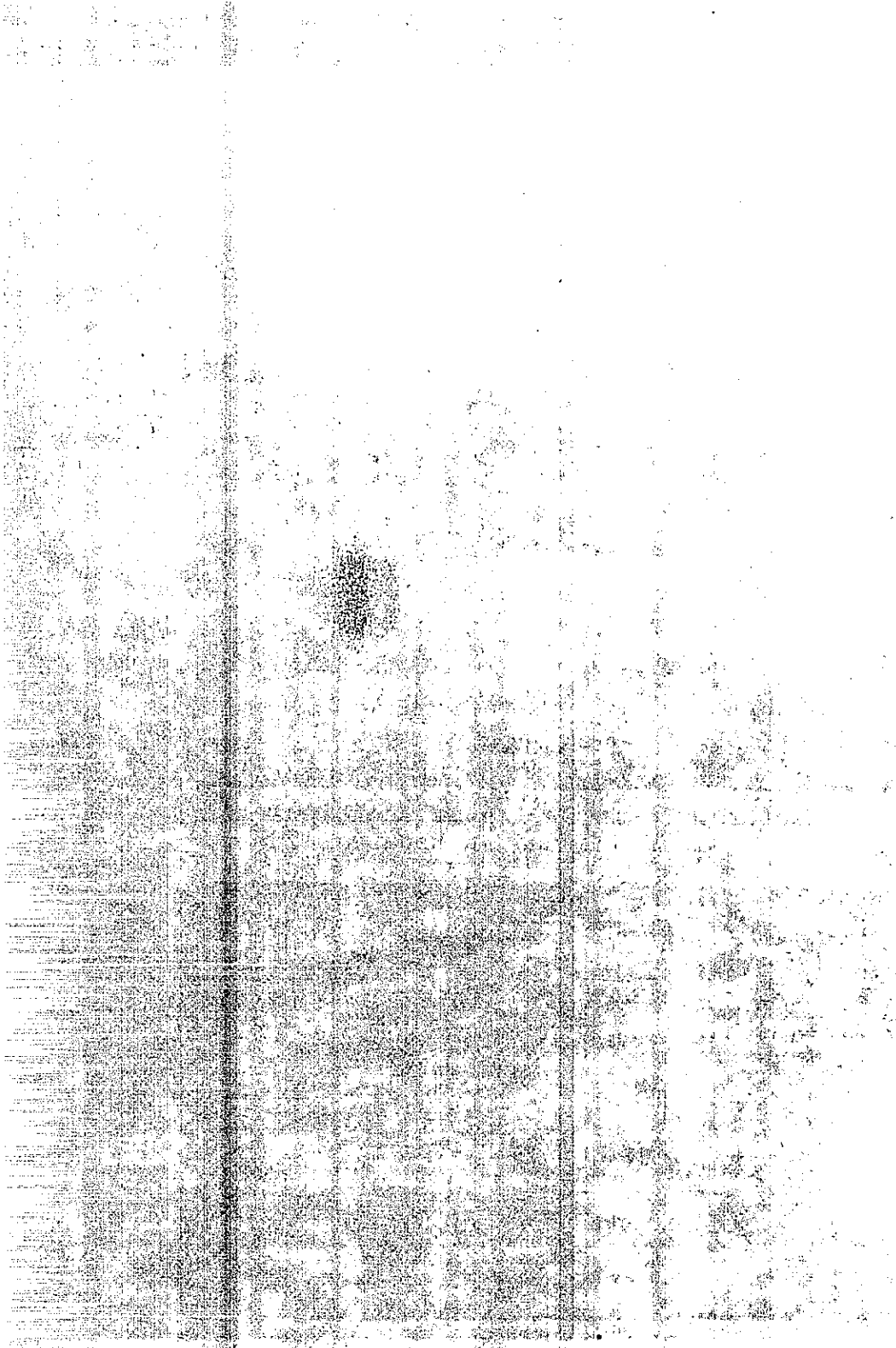

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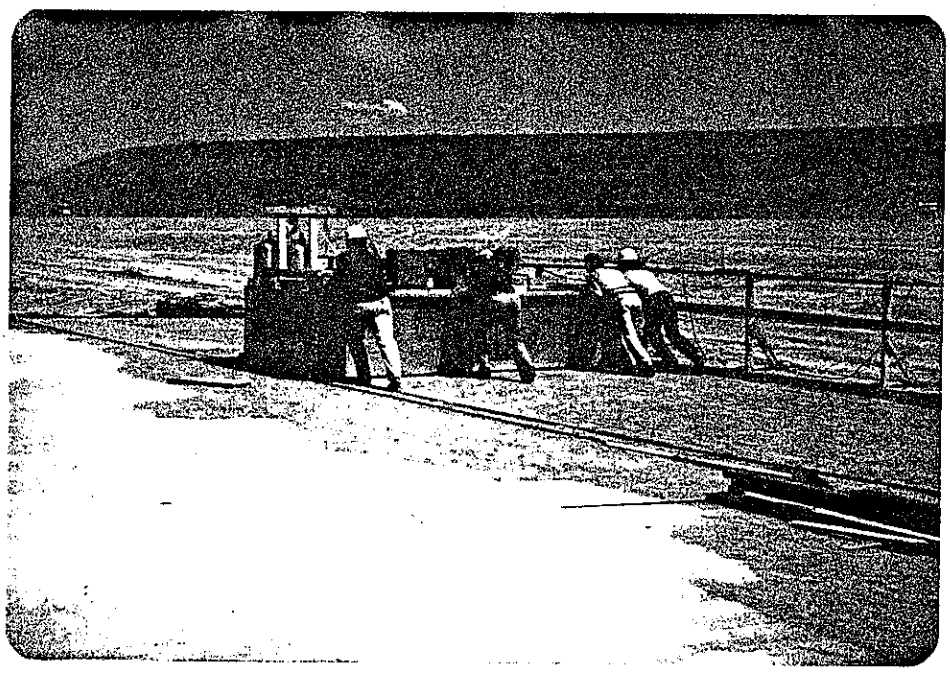

Figure 7 - Manpower Required to Move Infrared Heater

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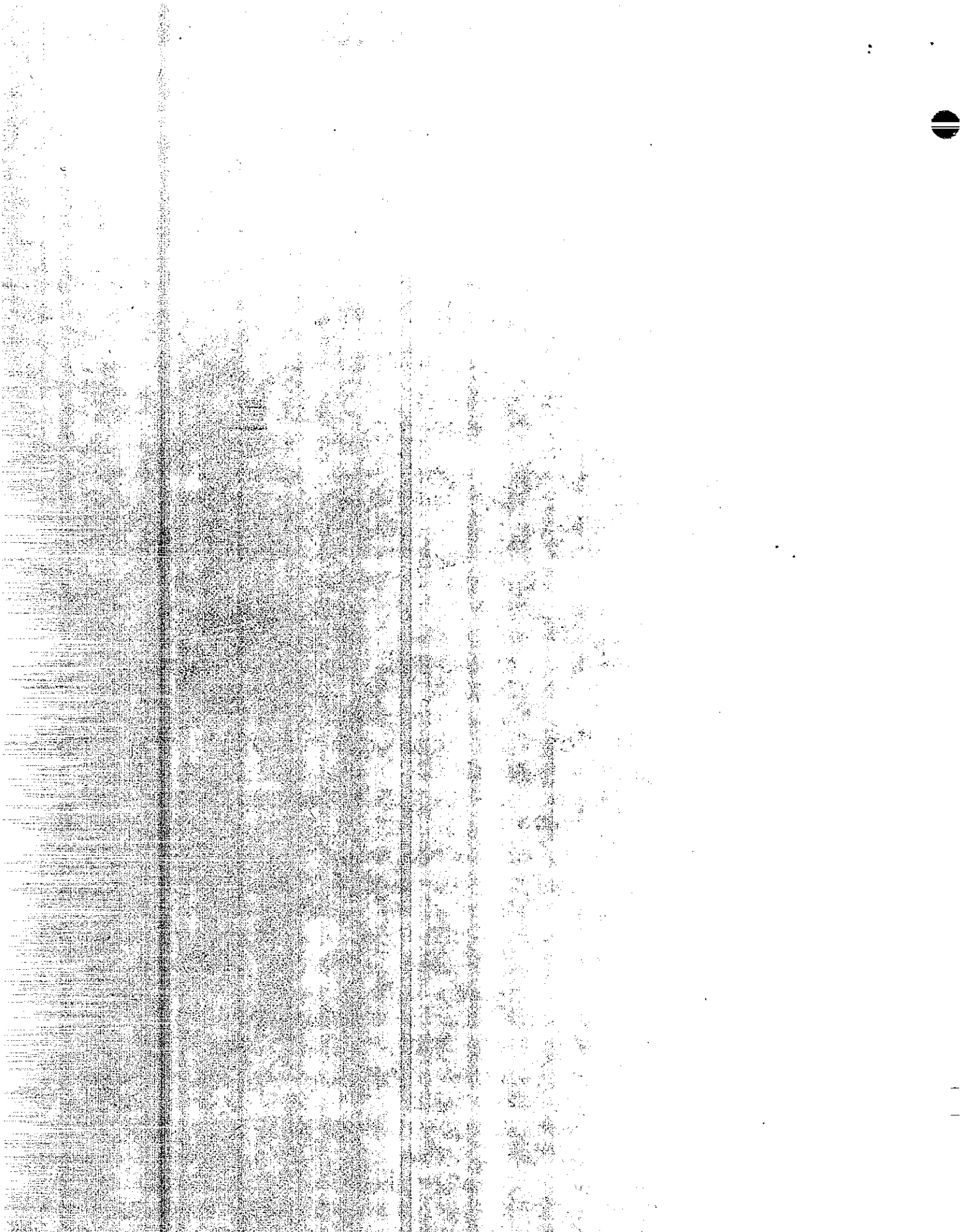

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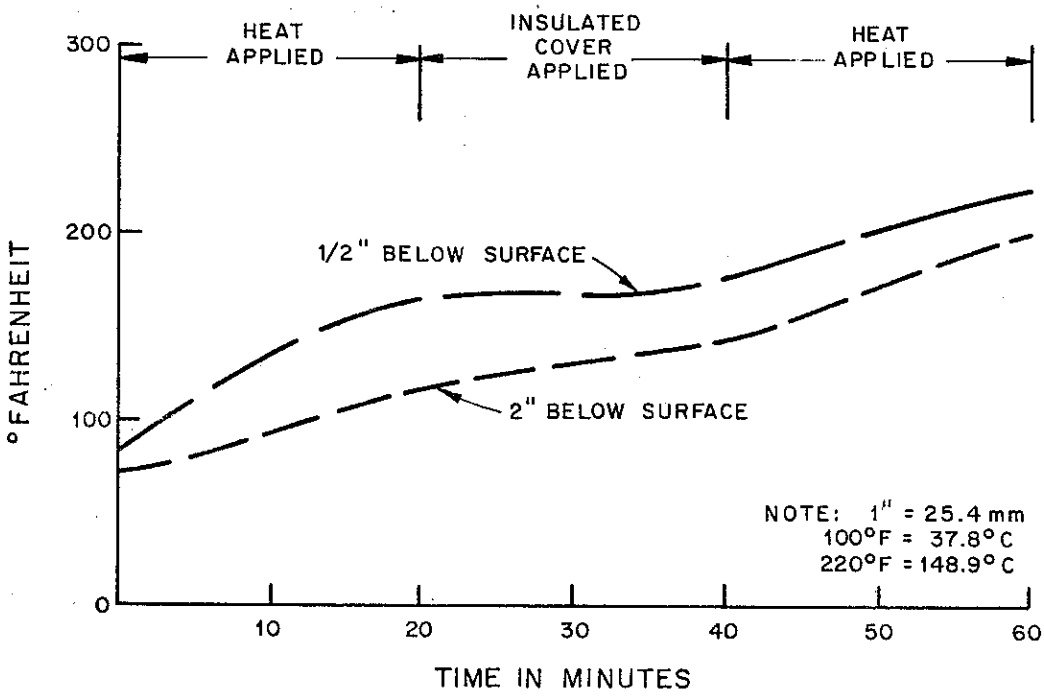

Figure 8

TYPICAL TEMPERATURES DURING DRYING CYCLE

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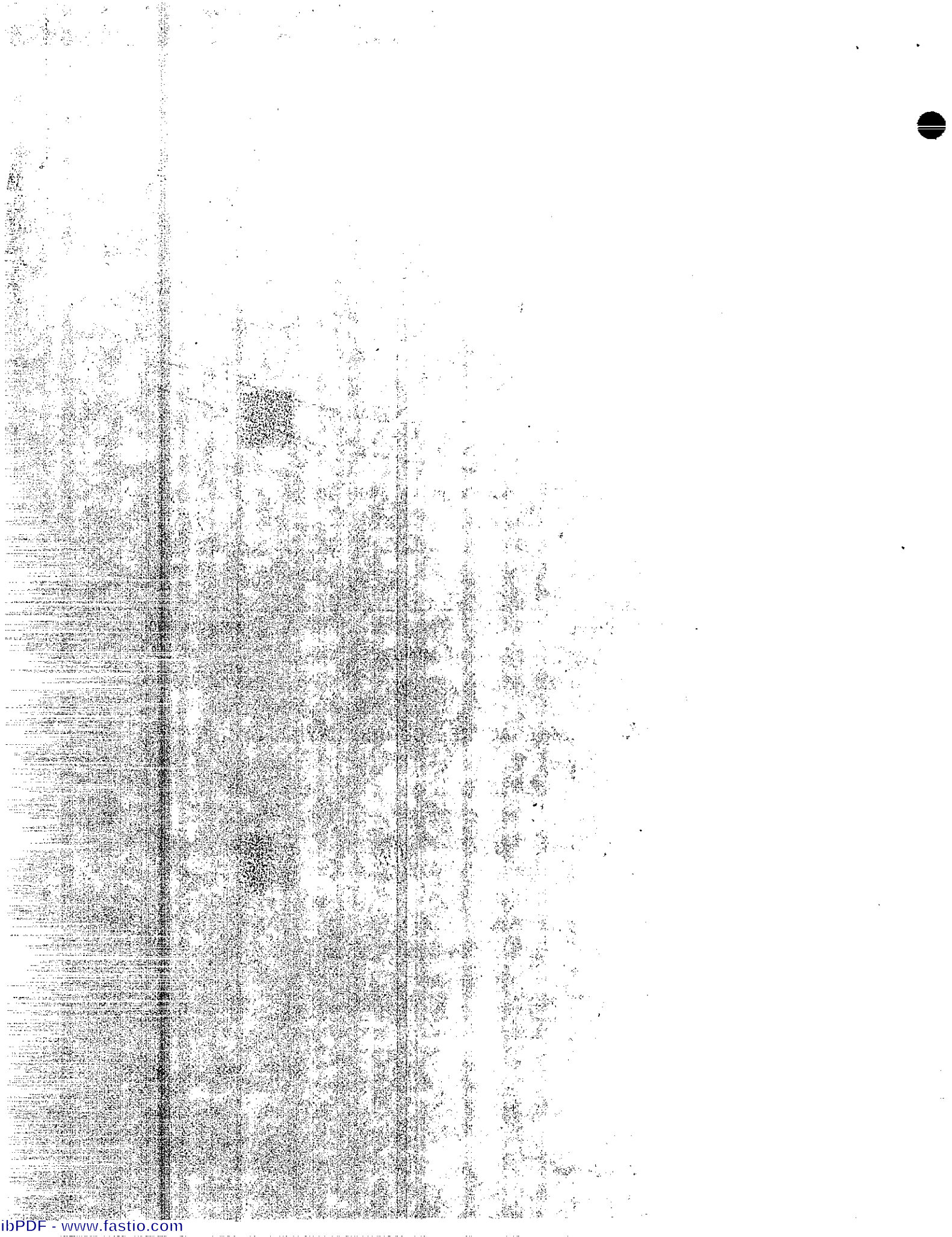

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Figure 9 - Initial Application of Monomer System to Sand Covered Bridge Deck.

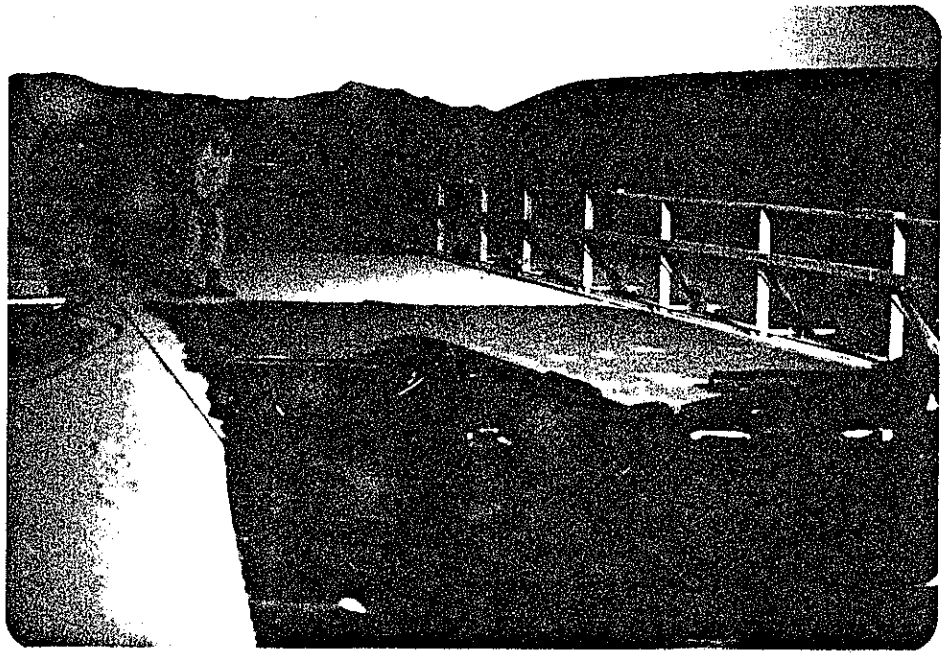

Figure 10 - Applying Monomer to Deck at Sundown and Covering Immediately With Black Polyethylene to Prevent Evaporation.

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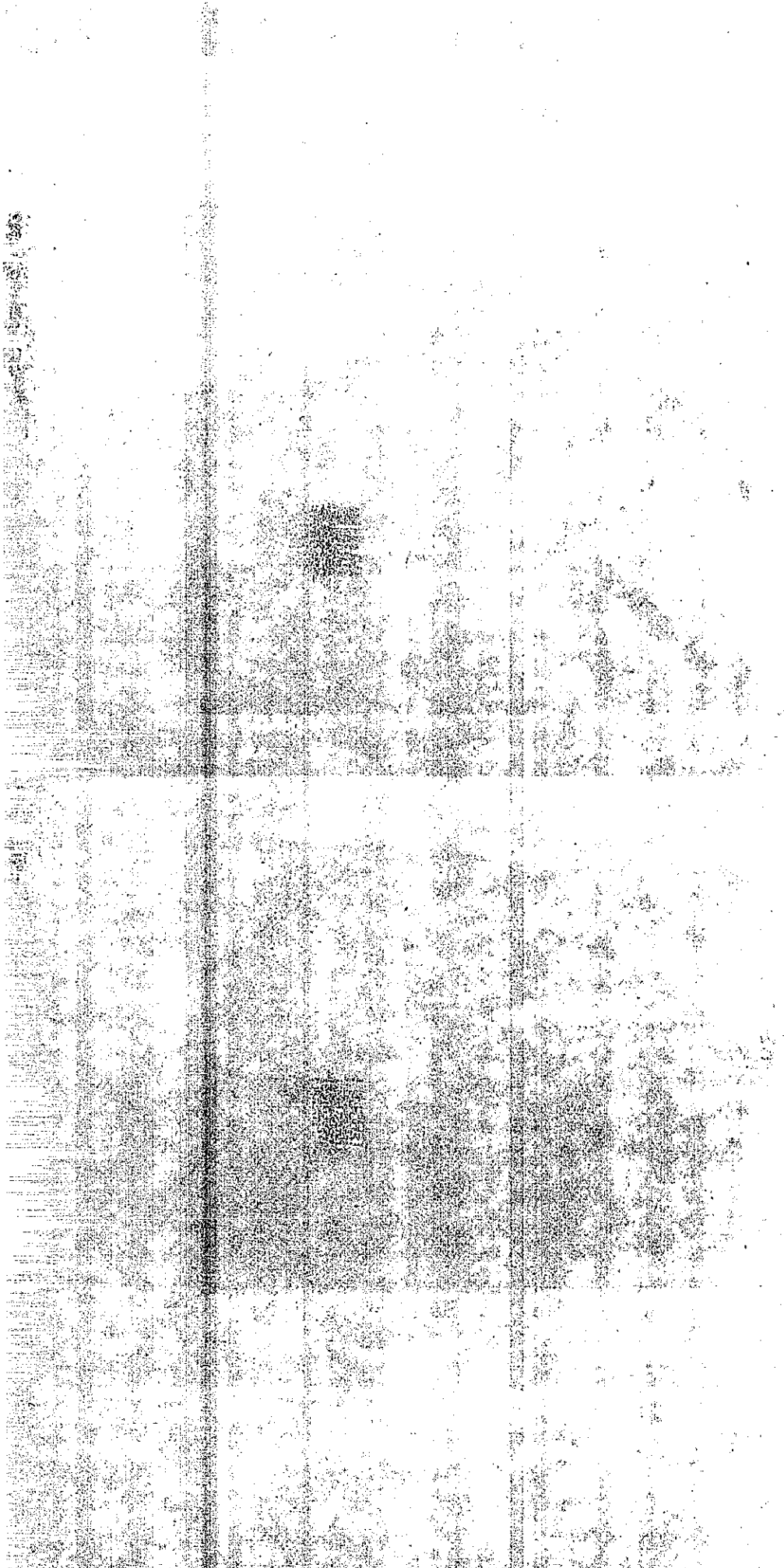

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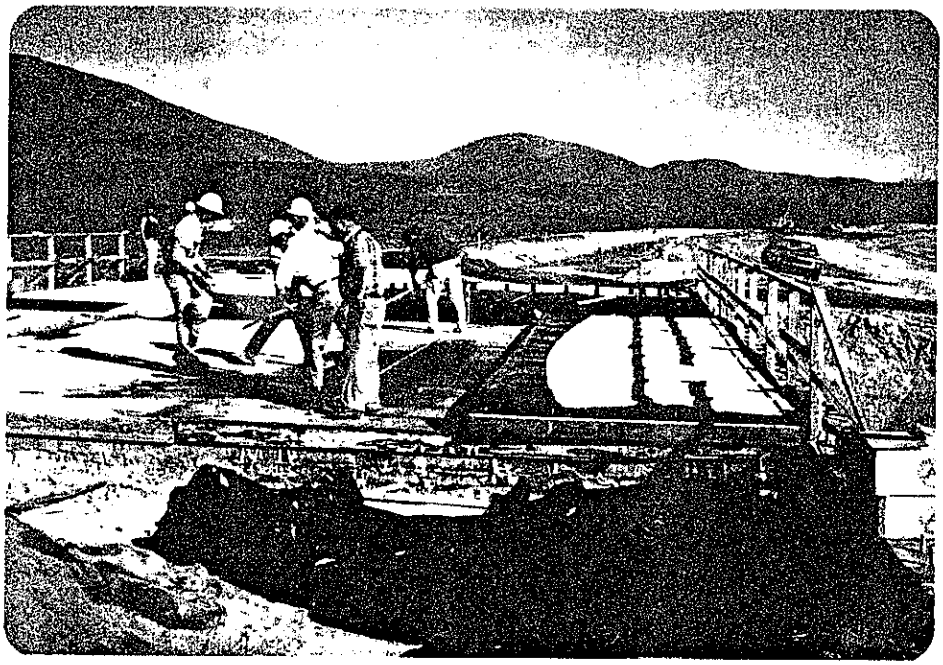

Figure 11 - Removal of Sand and Installation of 6 Inch (150 mm) High Bays to Contain Steam Heat.

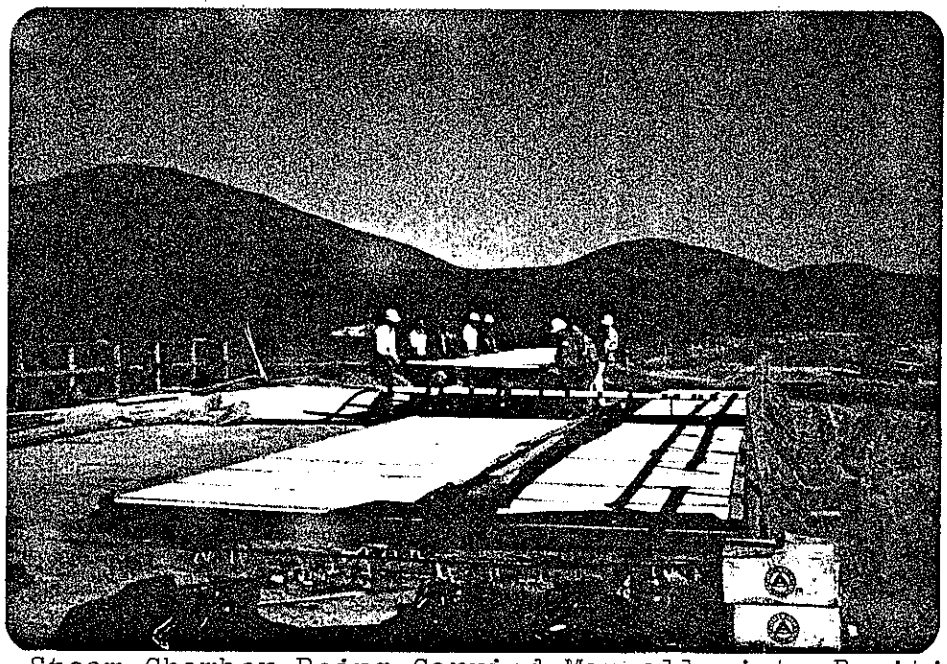

Figure 12 - Steam Chamber Being Carried Manually into Position. Steam Line and Manifold in Place.

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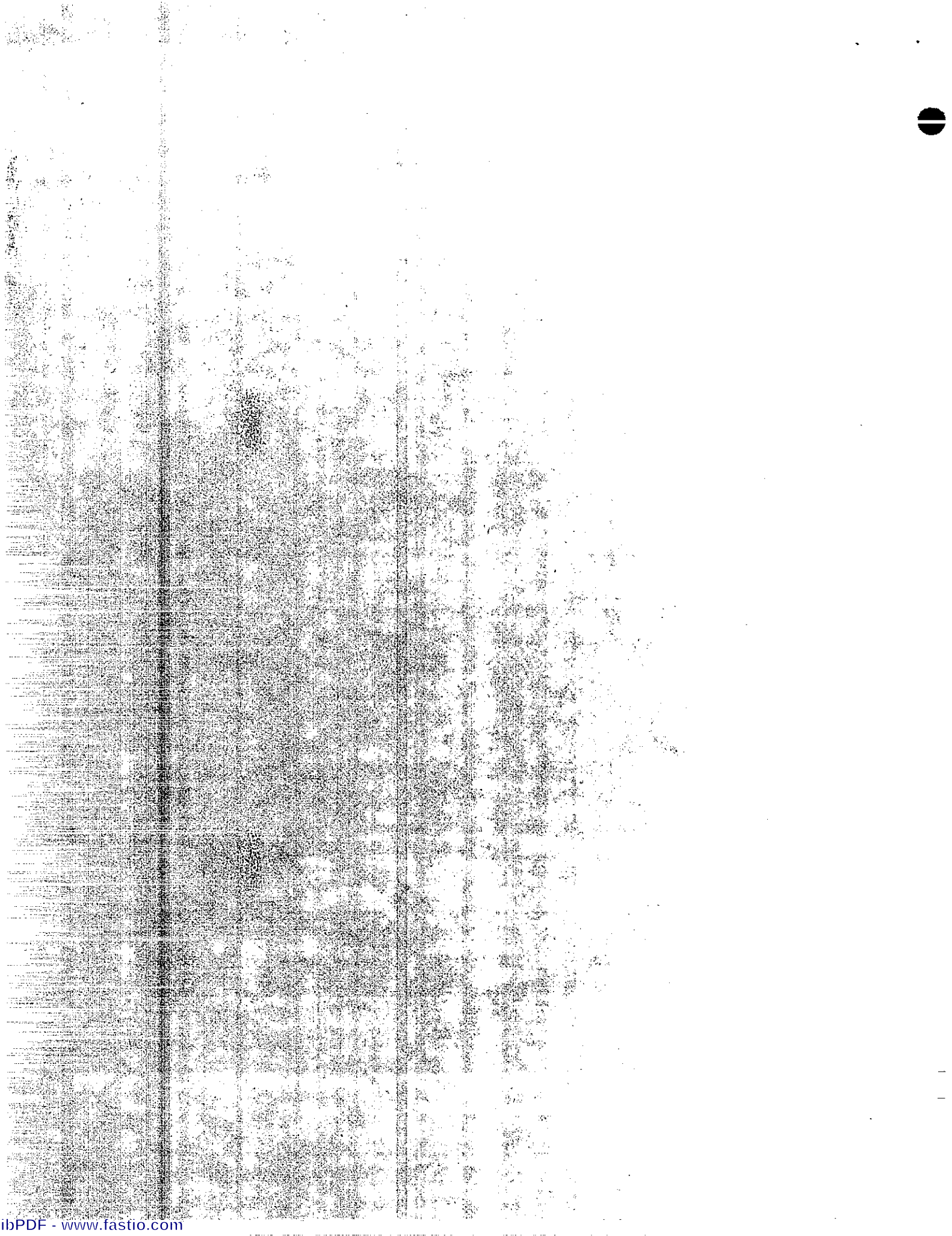

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Figure 13 - Steam Being Applied.

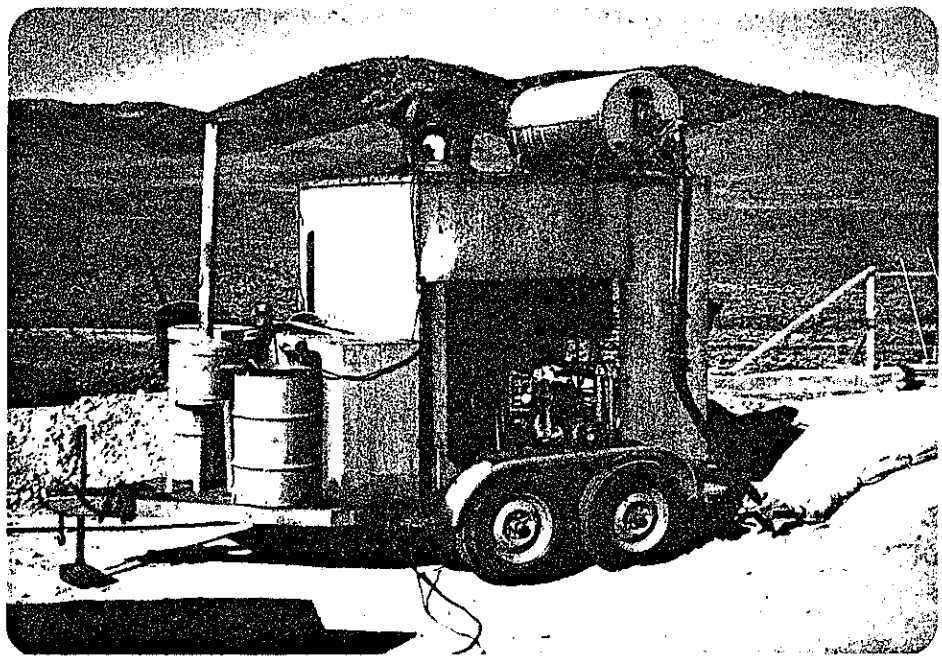

Figure 14 - Trailer Mounted Steam Generating Plant.

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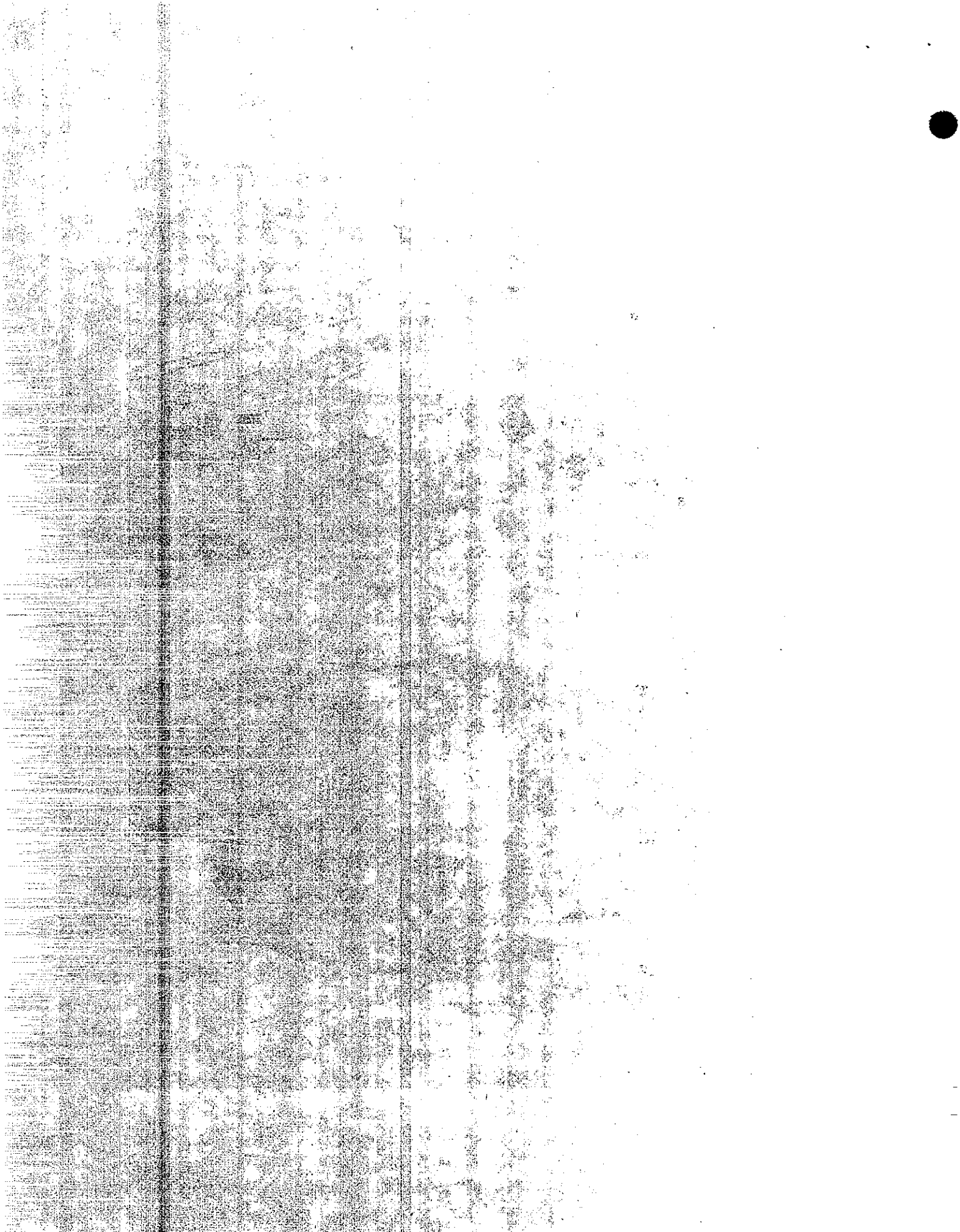

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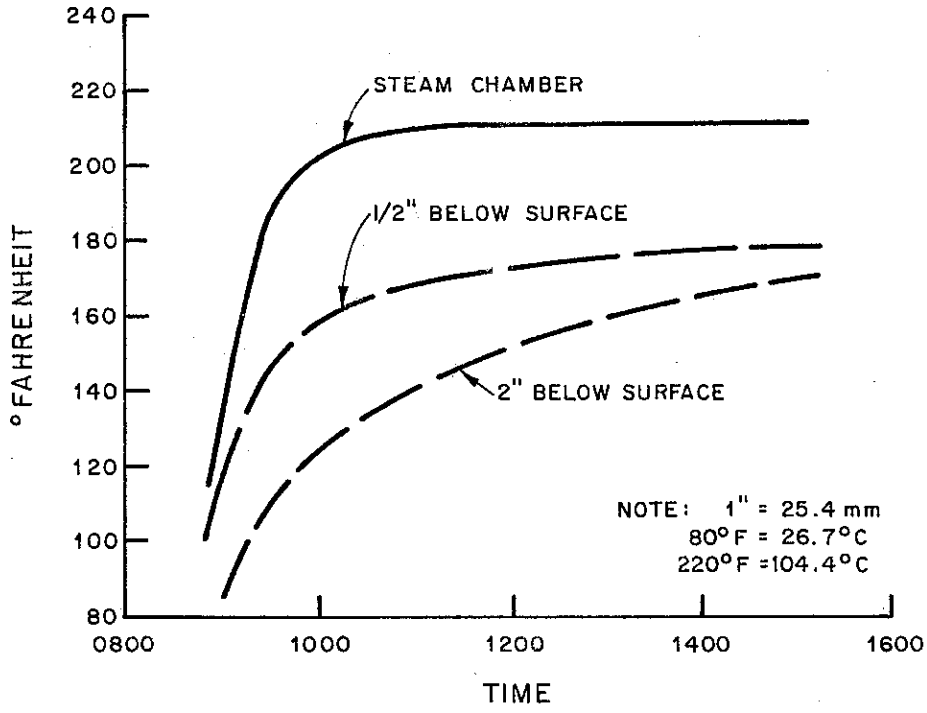

Figure 15

TYPICAL TEMPERATURES DURING POLYMERIZATION

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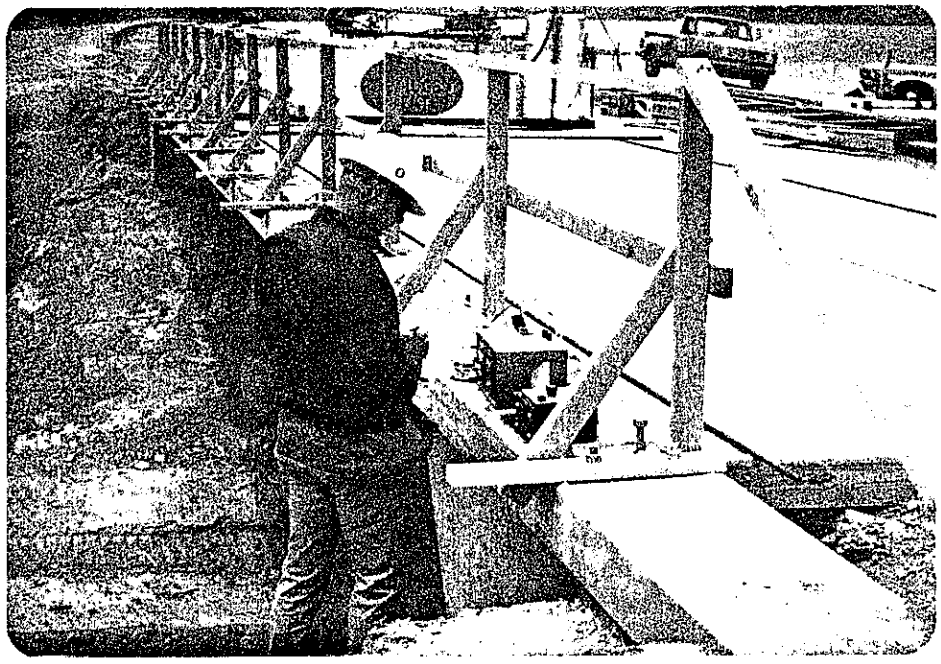

Figure 16 - Monitoring Temperatures.

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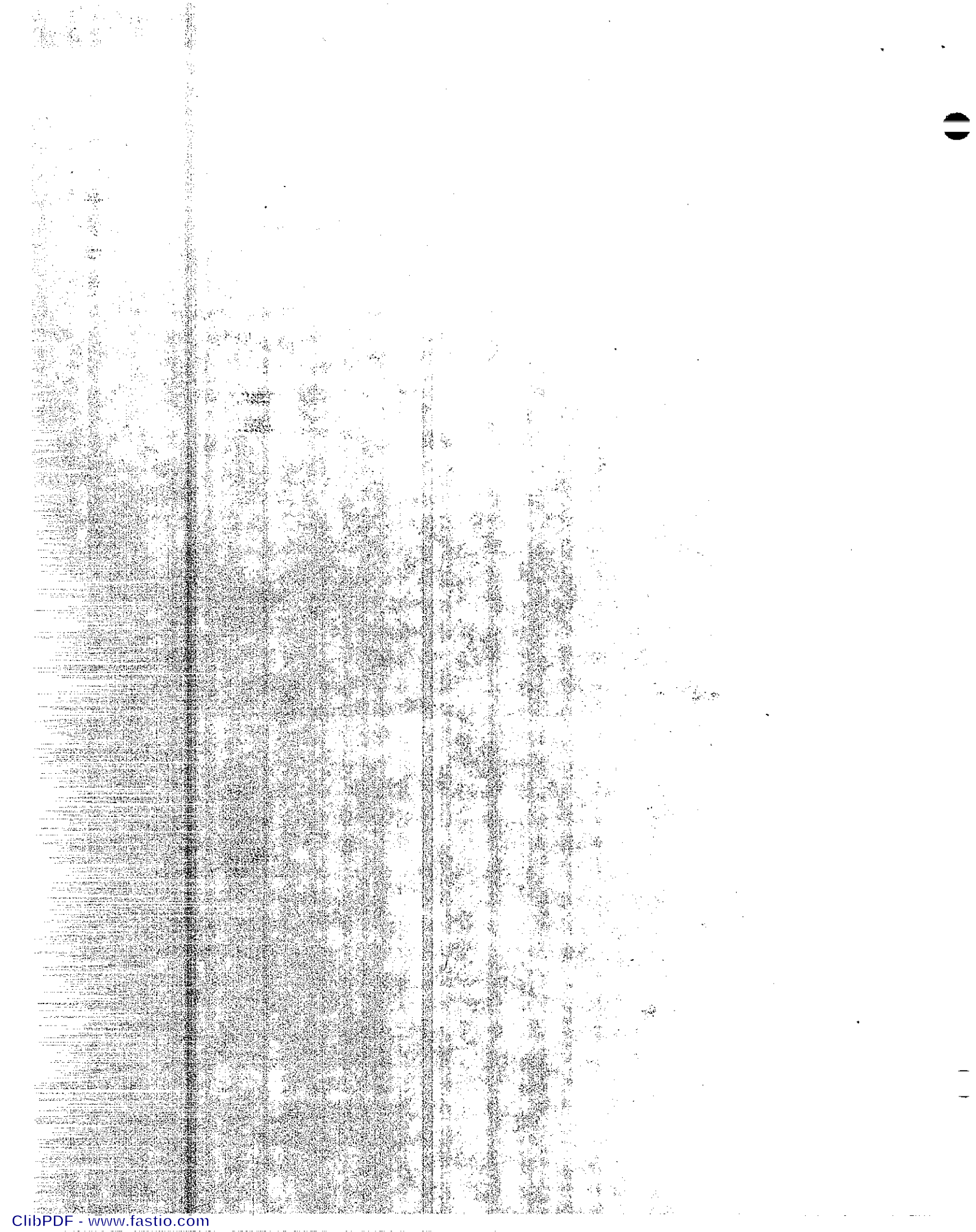

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APPENDIX A

Materials and Performance Specifications

A.1 Scope

The materials and performance specifications included in this appendix are designed to present the requirements for impregnating new concrete bridge decks to a minimum depth of 1 inch (25 mm) with a methyl methacrylate based monomer-catalyst system followed by in situ polymerization of the momer by steam heat.

A.2 Instrumentation

Prior to the actual placement of concrete for the bridge deck, thermocouples shall be installed to provide a means for monitoring the temperature of the concrete. Thermocouples shall be located at 1/2 inch (13 mm) and 1 1/2 inch (38 mm) below the surface of the finished bridge deck in sufficient number to assure an adequate representation of concrete temperature during the drying and polymerization phases.

A.3 Concrete Surface Preparation

Concrete bridge decks should preferably be cured using moisture proof sheet materials. Surface contaminants such as curing compounds, oil, asphalt, tar, or epoxy-type sealants shall be removed by sandblasting or by other approved means. After the removal of these materials or if the surface is not contaminated, minimum cleaning shall consist of removal of all leaves, trash, gravel, or other miscellaneous loose materials from the deck.

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A.4 Drying

Concrete shall be a minimum of 28 days old before drying begins. After the concrete surface area to be treated has been cleaned as in A.3 it shall be dried to a depth sufficient to permit a minimum of 1 inch (25 mm) of polymer penetration. The equipment used to accomplish drying shall consist of the use of an infrared type radiant heater, or other technique as approved by the Contracting Officer.

Drying shall be accomplished by maintaining a temperature of 200°F (93.3°C), 1-1/2 inches (38 mm) below the surface, for a period of 1 hour. During the drying process, care should be taken not to exceed a surface temperature of 400°F (204°C). If any cracking or spalling occurs as a result of the drying, the rate of heat application shall be reduced. To minimize the loss of heat from the deck following the moving of the heaters from one section to another, an insulating cover shall be placed over the previously heated areas. Temperature measurements shall be made as necessary to assure that the drying criteria are met.

Once the entire surface has been dried the deck shall be allowed to cool. The deck shall be covered with a layer of 6 mil (.15 mm) thickness polyethylene to prevent the intrusion of moisture during the evening hours.

A.5 Cooling

After the concrete bridge deck has been dried it shall be cooled prior to monomer application.

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During the cooling and impregnation cycles, the dried bridge deck concrete shall be protected to prevent moisture from reentering the concrete. It may be necessary to repeat the drying and cooling cycles prior to monomer application should moisture reenter the concrete as determined by the Contracting Officer.

A.6 Impregnation

Following the drying and cooling cycles, the concrete surface to be impregnated shall be uniformly covered with a 1/4- to 1/2-inch (6 to 13 mm) thick layer of washed, dry (moisture content not greater than 1 percent by weight) graded sand such as commercial concrete sand.

The temperature in the upper 3 inches (75 mm) of the concrete deck shall not exceed 85°F (29.5°C) at the time of monomer application nor at any time during the impregnating cycle.

The initial monomer application shall be made at a rate sufficient to uniformly saturate the sand layer to a slight excess without applying so much monomer that it flows over the sand surface to the bridge deck drainage features. The initial monomer application rate should be 0.7 to 0.9 pound of monomer per ft^2 (3.4 to 4.4 kg/m^2) of bridge surface. However, sand layer thicknesses, sand particle size, and bridge deck super elevation may necessitate application rate adjustment to achieve the described saturation. A second application of monomer shall be made 2 to 3 hours after the initial application. The second application shall be made at a rate, normally 0.2 to 0.4 pound of monomer per ft^2 (1 to 2 kg/m^2) of surface, sufficient to fully saturate the sand

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layer. Following the second application, the monomer shall be allowed to soak into the concrete for an additional 4 to 5 hours, total impregnation time not less than 8 hours, or until sufficient monomer penetration has occurred to result in 1 inch (25 mm) of polymer impregnation.

In order to protect the monomer-saturated sand from the polymerizing effects of direct and indirect solar radiation, monomer application and subsequent soaking shall occur during the time period sunset to sunrise unless the contractor provides shielding, as approved by the Contracting Officer, to prevent solar radiation from reaching the bridge deck area being impregnated. Immediately following each monomer application, a continuous polyethylene membrane, a minimum of 10 mils (0.25 mm) thick shall be placed over the monomer-saturated surface to reduce monomer evaporation. This membrane shall remain in place, except for the short periods of monomer application or surface inspection, throughout the impregnation cycle, and until the polymerization cycle is complete. Monomer saturated sand shall be removed prior to the polymerization process, taking care to prevent evaporation of monomer from the deck surface.

A.7 Polymerization

Polymerization of the monomer impregnated into the concrete shall be accomplished by uniformly heating the treated concrete to a surface temperature of at least 165°F (74°C) and not exceeding 185°F (85°C). This temperature range shall then be maintained for a minimum of 2 hours at a depth of 1 1/2 inches (38 mm). Steam heat or other method as approved by the Contracting Officer shall be used to accomplish heating of the concrete for polymerization.

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A conduit system, for carrying steam shall be palced on the deck and covered with a prefabricated chamber or chambers to effectively contain the steam. The steam generator and piping system shall be capable of supplying a sufficient uniform heat to produce a temperature of 165°F (74°C) at a depth of 1 1/2 inches (38 mm) within 4 hours of the start of the steaming process.

A.8 Monomer System

The monomer system shall be composed of 90 percent by weight methyl methacrylate (MMA) and 10 percent by weight trimethylolpropane trimethacrylate (TMPTMA). A polymerization catalyst, 2,2'-azo-bis-isobutyronitrile shall be added to this monomer system at the rate of 2 parts catalyst to 100 parts monomer by weight, or as specified by the Contracting Officer.

A.9 Monomer Specifications

MMA shall meet the following requirements:

Formula	$CH_2:C(CH_3)\ COOCH_3$
Inhibitor	25 p/m hydroquinone (HQ)
Molecular Wt.	100
Assay (Gas Chromatography) %	99.8 min
Density	7.83 lb/gal (9.38 Kg/liter)
Boiling point	212°F (100°C)
Flash Point (Tag, ASTM D1310)	55°F (13°C)

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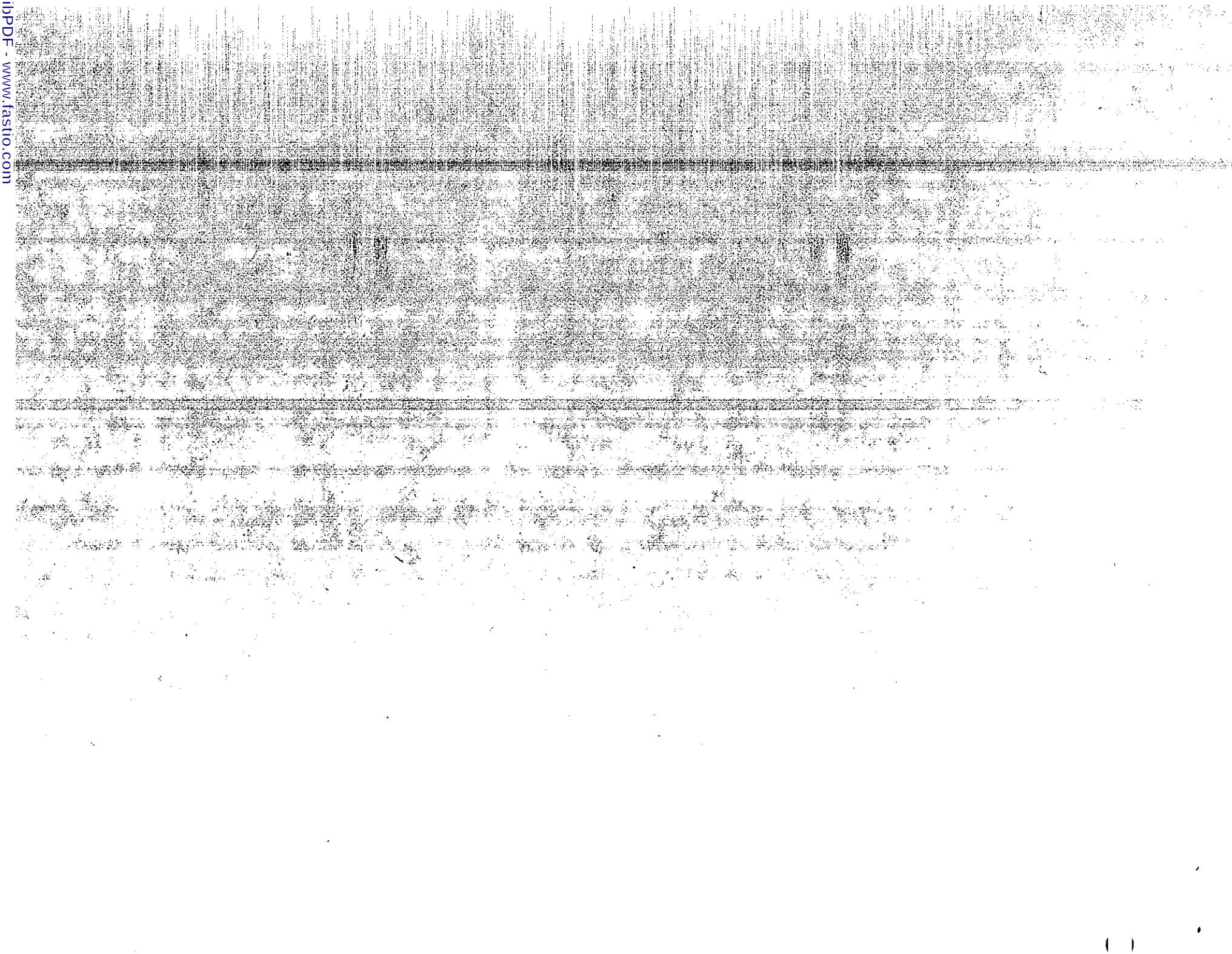

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TMPA shall meet the following requirements:

Formula	$(CH_2=CH_3-COOCH_2)_3\ CCH_2CH_3$
Inhibitor	100 p/m hydroquinone (HQ)
Assay, %	95.0 min
Density	8.82 lb/gal (10.58 Kg/liter)
Flash point (Cleveland, ASTM D92)	Greater than 300°F (149°C)

The polymerization catalyst shall be 2,2'-azo-bis-isobutyronitrile.

The contractor shall provide the Contracting Officer with manufacturer's certifications that the monomer and catalyst meet the above specifications. Representative samples of the monomer system components shall be delivered to the Contracting Officer at least 30 days prior to use. At the Contracting Officer's option, these samples will be tested to determine specifications compliance.

Monomer system components shall be used within 6 months after manufacture.

A.10 Monomer - Catalyst Storage and Handling

The monomers, MMA and TMPTMA, shall be stored in their original shipping containers, or in other clean containers as approved by the Contracting Officer. Maximum monomer storage temperature shall not exceed 90°F (32°C). The storage area shall be selected to provide protection from direct sunlight, fire hazard, and oxidizing chemicals. Sufficient ventilation shall be maintained in the storage area to prevent the hazardous buildup of monomer vapor

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concentrations in the storage air space. The polymerization catalyst shall be stored in accordance with manufacturer's recommendations but in no event shall the catalyst storage temperature be allowed to exceed 32°F (0°C). Personnel exposed to monomer or monomer vapor shall use minimum protective equipment as follows: Safety eye glasses, impervious gloves and aprons, and rubber boots as required. As determined by the Contracting Officer, personnel may be required to use full face protective shields and/or self-contained respiratory equipment. All personnel handling the monomers or catalyst shall be throughly trained in their safe use in accordance with manufacturers' recommendations.

Unsafe handling practices will be sufficient cause to discontinue work until the hazardous procedures are corrected. The handling and use of monomer shall in all cases comply with the requirements of applicable Federal, state, and local safety requirements and ordinances.

A.11 Monomer Mixing

The monomers MMA and TMPTMA may be premixed in the specified ratio and stored prior to use. Storage of premixed monomer shall be as required in Section A.10. All monomer mixing and transfer equipment shall be of explosion proof design and provided with electrical ground cables. Monomer transfers shall be from bottom to bottom of the vessels or through dip pipes in the vessels to prevent the buildup of static charge during transfer. Pipe fittings, valves, pump impellers, or other equipment which will come into contact with monomer, shall not be made of copper or brass. The monomer mixing area shall be free of sources of ignition and well ventilated.

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Spilled monomer shall be contained with absorptive material such as vermiculite or dry sawdust and removed with nonsparking equipment.

A.12 Catalyst-Monomer Mixing

The polymerization catalyst shall be mixed with the monomer system immediately prior to use. Monomer system temperature at the time of catalyst addition shall not exceed 85°F (29.5°C). Mixing will be accomplished with explosion proof equipment in electrically grounded containers in a well ventilated area.

Catalyzed monomer, not used within 4 hours of catalyst addition, shall be stored in an explosion proof, refrigerated storage facility at a maximum storage temperature of 0°F (-18°C) until it can be used or destroyed as approved by the Contracting Officer.

A.13 Treatment Process and Quality Control Reports

At least 30 days prior to beginning the bridge deck impregnation process the contractor shall deliver to the Contracting Officer a written Procedures Report describing his planned treatment procedures. Included in this report shall be a detailed description of the drying, impregnation, monomer mixing and storage, polymerization and quality control procedures, facilities, and equipment the contractor intends to use to treat the bridge deck. The Contracting Officer will review this report and at his discretion provide approval or disapproval of the plan within 15 days of the date of receipt. In no event shall the contractor proceed with the surface

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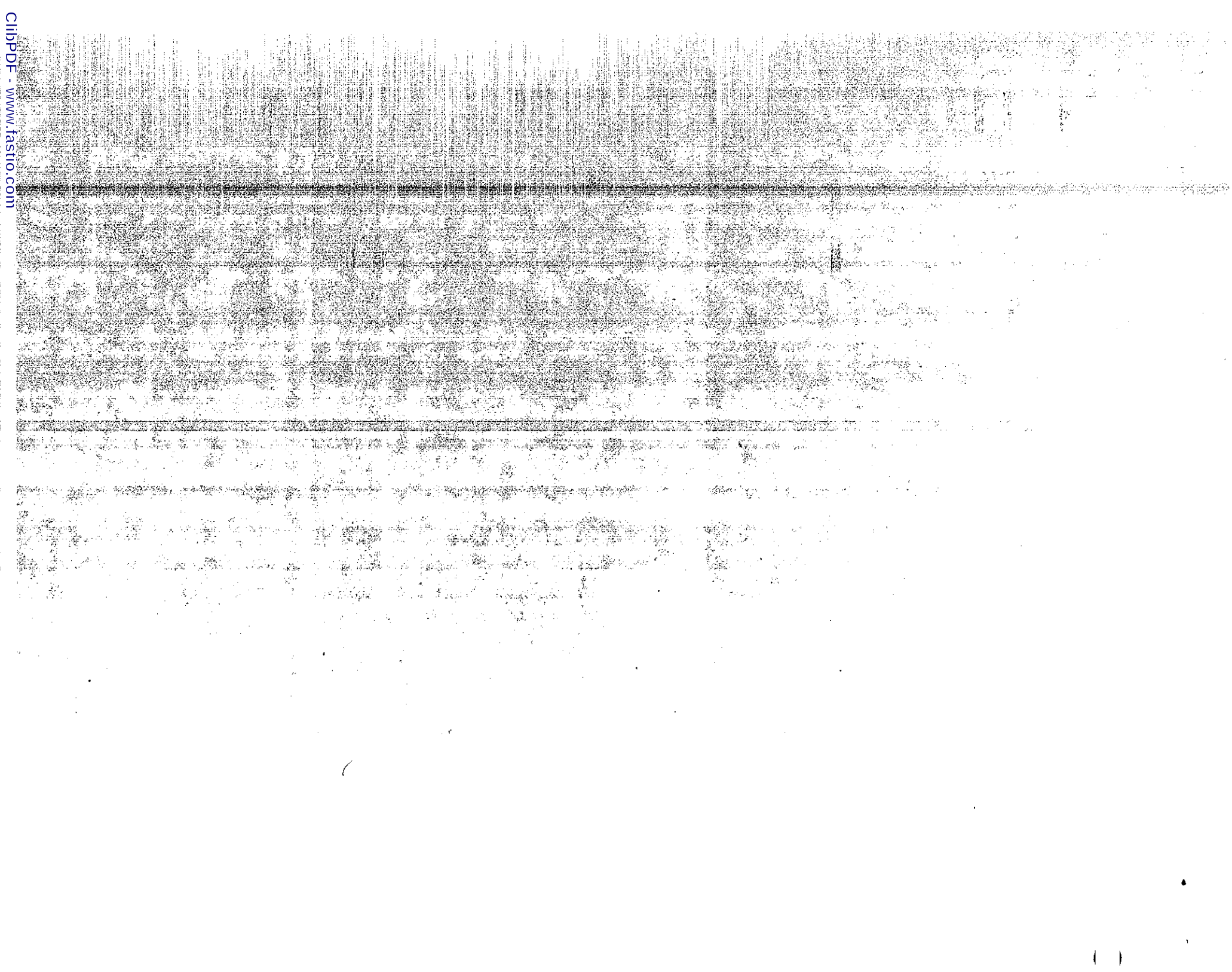

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impregnation treatment until approval of his procedures, materials, and equipment has been received.

During the drying, cooling, impregnation, and polymerization cycles, the contractor shall obtain and supply to the Contracting Officer concrete temperature data to ± 5°F (2.8°C) from at least nine points uniformly spaced over and on the surface of the treated concrete and at least one set of points vertically spaced 1, 2, and 3 inches (25, 50, and 75 mm) below the concrete surface at the approximate center of the treated area.

These data shall be in the form of a continuous record or periodic readings recorded at 1-hour intervals. The technique and equipment used to obtain temperature data shall be described in the written Procedures Report above and subject to Contracting Officer approval.

The contractor shall maintain and supply to the Contracting Officer monomer and catalyst records listing the dates of manufacture, storage temperatures, date of use and application rates, and quantities as applied to the bridge deck.

Following completion of the surface impregnation treatment process, on any portion of the bridge, the contractor shall obtain and deliver to the Contracting Officer nine cores, a minimum of 2 inches (50 mm) in diameter and of sufficient length to include the entire depth of the polymer impregnation. The cores shall be taken from the bridge at the locations of the temperature sensors as described above and identification to temperature data.

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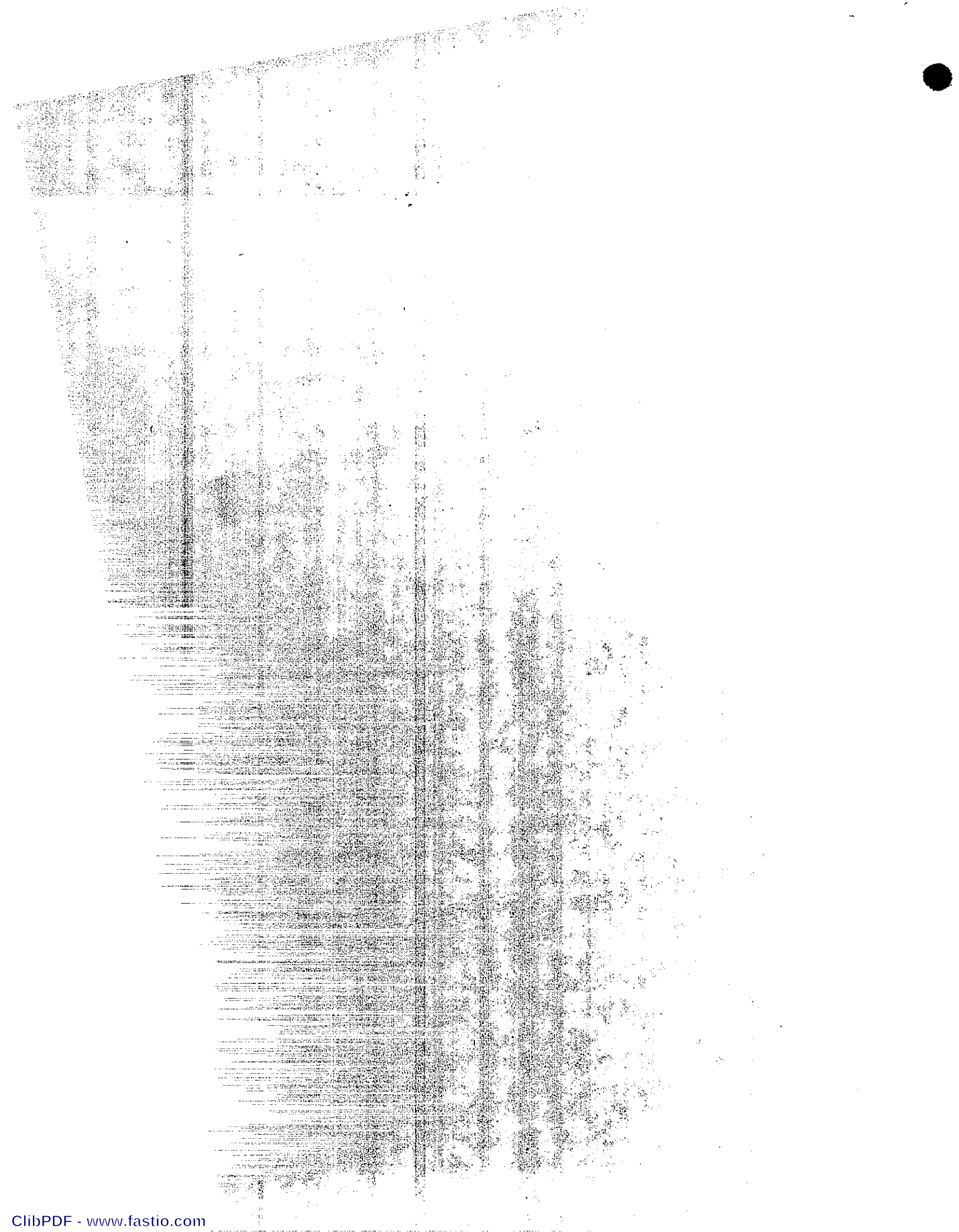

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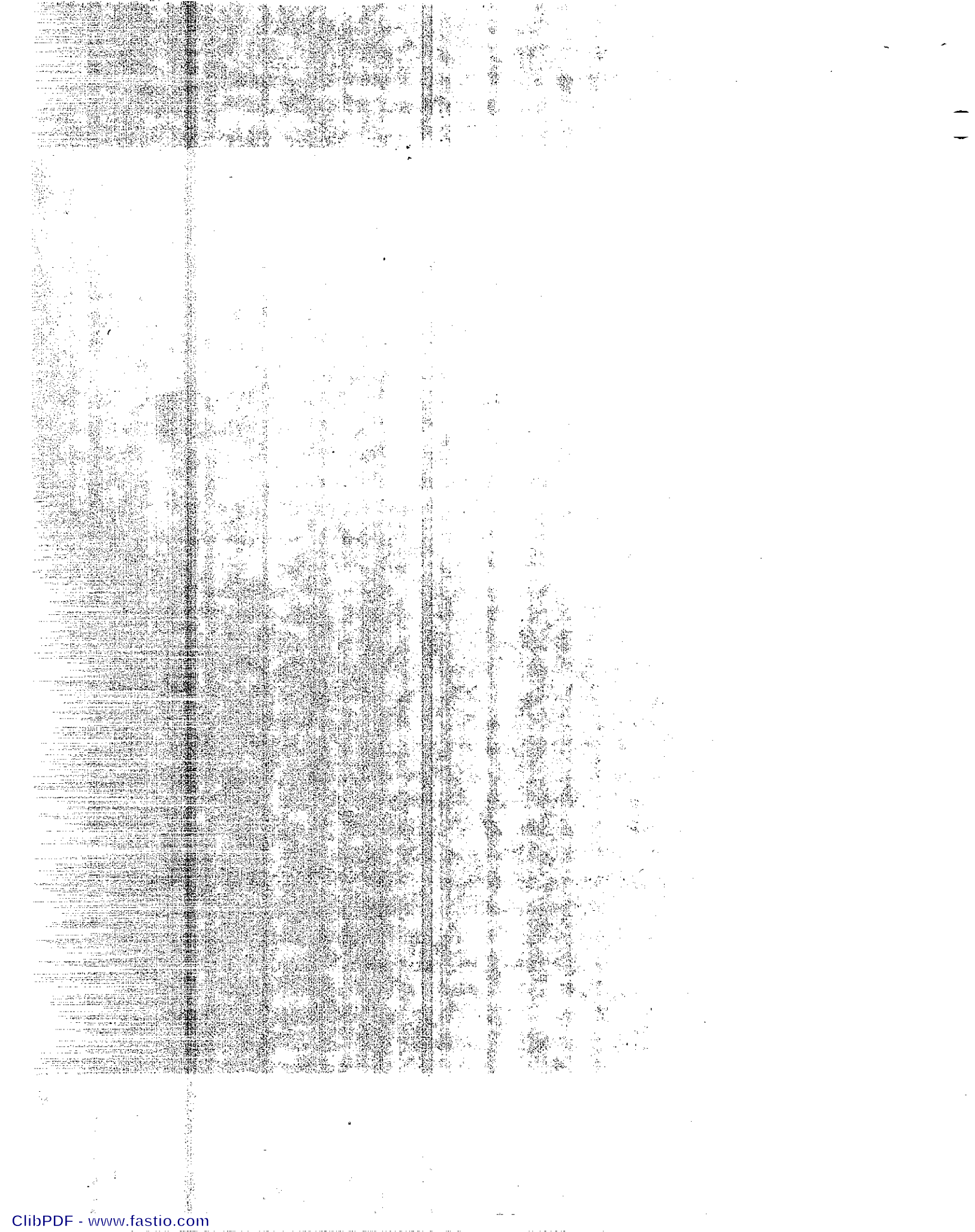

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A.14 Basis of Payment

The accepted quantities of concrete deck surface impregnated and polymerized as above will be paid for at the contract unit price per square yard of surface, treated to a minimum depth of 1 inch (25 mm) which price and payment will be full compensation for all work performed under these specifications. No additional payment over the unit bid price will be made for any deck surface area which has a polymer penetration greater than 1 inch (25 mm).

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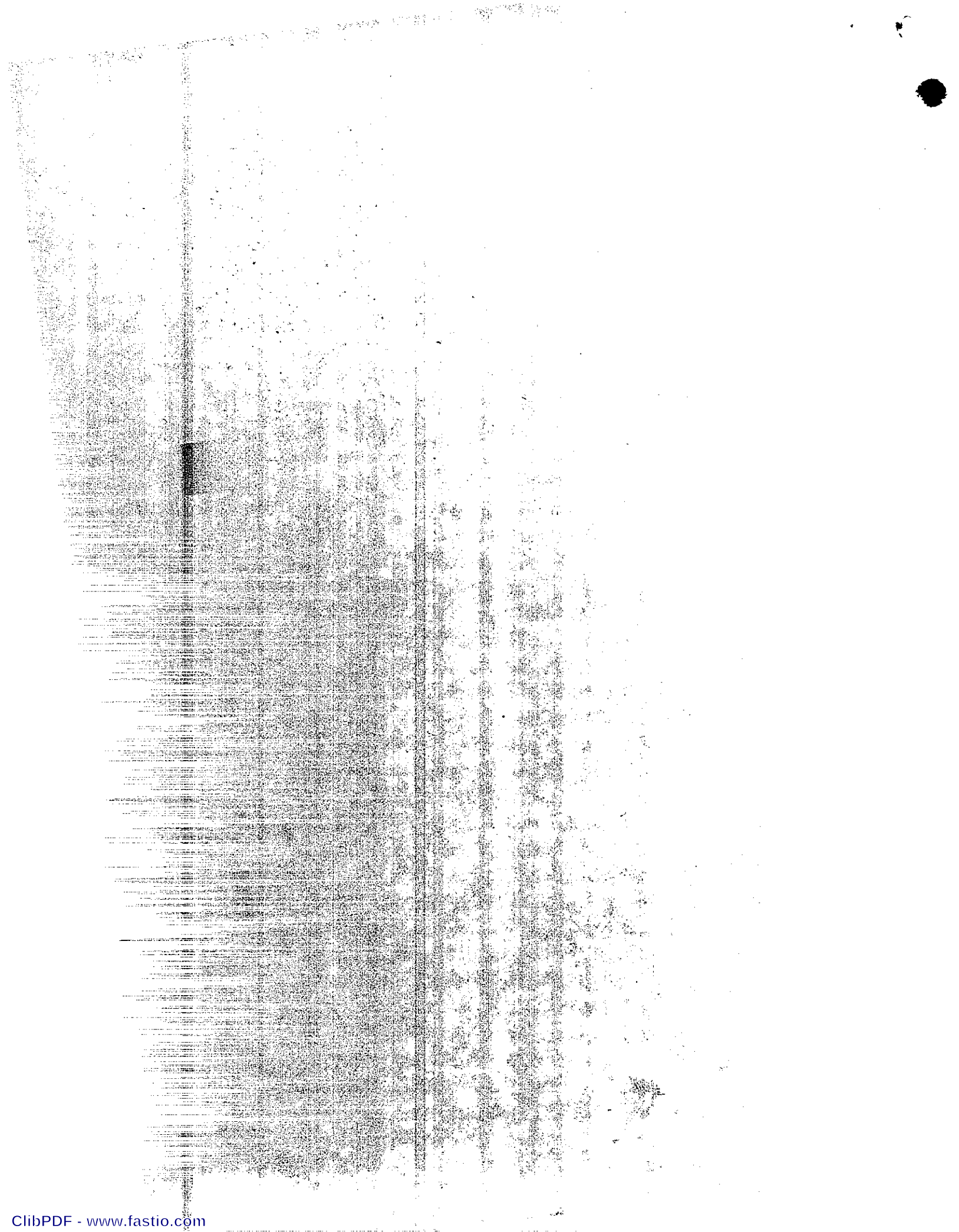

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