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A CASE STUDY OF THE CAUSE OF ROOF MOISTURE DAMAGE

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ABSTRACT

The purpose of this paper is to describe the results and implications of a field investigation of roof moisture damage in three flat-roofed Oregon Department of Fish and Wildlife buildings near Medford, Oregon. The roofs were wood-framed with plywood inner and outer deck surfaces, R-11 batt insulation, and a hypalon rubber membrane covering the outer plywood surface. The buildings were constructed in the early 1970's. Recently it became apparent that there was a roof moisture damage problem because of numerous cases of water dripping from ceilings into the interior of the buildings, a hole in the outside surface of the roof of one of the buildings, and ice damage inside a building with a freezer room. A site visit and inspection was undertaken in June 1985 to determine the probable cause. The two major candidates were a leak of water from the outside into the roof cavity that was causing leakage and possible structural damage due to wood decay, or an accumulation of moisture in the roof cavity from condensation of water vapor migrating in the wintertime from the inside of the building toward the outside. The field investigation involved visual inspection, making openings into the roof cavity, and wood moisture content measurements. Numerous leaks of water from the roof cavities into the interiors of the buildings were observed as were high wood moisture contents in some locations and even some wood decay and structural damage. The roof ventilation system also was found to be impaired because ventilation air was inadvertently blocked during construction. Details of the findings will be presented. All the evidence strongly suggested that the roof moisture damage was caused by the fact that, while not easily observable, the exterior hypalon rubber roof surface deteriorated to such an extent that water was slowly leaking into the roof cavity. Comments will be made concerning the ensuing roof repair and ways to avoid moisture and ventilation problems with flat roof construction. Further, the implications of the results of this case study on the development of appropriate standards to prevent future reoccurrences in similar situations will be discussed. Finally, while condensation is often blamed for roof moisture damage, the evidence in this case indicates that it was not a factor.

INTRODUCTION

On June 4, 1985, a one day site visit was made (by the lead author acting as a consultant) to the Cole Rivers Hatchery at Trail, Oregon to inspect roofs that were failing due to intrusion of moisture. Prior to the site visit it had become apparent that there was a roof moisture damage problem because of numerous roof leaks, a hole caused by decay in the outside surface of the hatchery building roof, and ice damage in the food service building freezer room. However, cursory inspection of the roof surfaces did not indicate any roof leakage. While the buildings were constructed in the early 1970's, no moisture/leak problems were noted until the year or two before the visit. The purpose of the site visit was to inspect the roofs and existing damage, to try and determine the extent of the damage and the probable causes, and to make recommendations regarding repairs.

Because the site visit/inspection trip was limited to only one day, it was decided to concentrate the inspection efforts in the hatchery building that had a hole in the roof and the mechanical-electrical building where a previous roof leak had existed. Near the end of the day the food service building was briefly examined. No other buildings were inspected.

MOISTURE PROBLEM ASSESSMENT PROCEDURE

The first thing done upon arrival at the hatchery site was to visually inspect the roofs and buildings and discuss the past history of moisture problems to see if a moisture problem really existed. It soon became clear that there was a problem, so the next step was to determine the probable cause. The two major candidates were a leak of water from the outside into the roof cavity that was causing leakage and possible structural damage due to wood decay or an accumulation of moisture in the roof cavity from condensation of water vapor migrating in the wintertime from the inside of the building toward the outside.

During the inspection of the interiors of the buildings the ceilings and exposed wood beams were examined for water stains and/or water drip marks and/or other signs such as rusting. In addition, a search was made for potential interior moisture sources. On the roof exterior, the hypalon rubber exterior roof surface membrane was carefully inspected for leak sites. Lastly, a resistivity-type moisture meter was used to determine the moisture content of various wood members, including the interior ceiling plywood and laminated beams as well as numerous wood members exposed when roof cavities were opened up for inspection of the interior wood members. Wood moisture content readings of about twenty percent or lower are of no concern. Readings of 25-30 percent or greater indicate the wood is abnormally wet, and there is a concern about the possibility of wood decay (dry rot) and structural damage.

DESCRIPTION OF ROOF CONSTRUCTION

The roofs of the buildings are for the most part flat, except for slight sloping for drainage (see Figures 1 and 2). They consist of 3/8 in. (9.5 mm) 4x8 plywood sheets on the bottom (or inside) surface as well as the top (or outside) surface. The top surface is slightly sloped to drains (1/4"/ft min.). The two plywood deck surfaces are separated by 2x6 rafters connected to the bottom plywood with another 2x6 nailed onto the side of the lower rafters to provide the proper top plywood surface slope. The roof cavity contains R-11 mineral wool batt insulation with its aluminum vapor retarder facing insert stapled on the inside surface (thus the vapor retarder is not continuous). The roof cavity has minimal ventilation consisting of a one inch wide soffit vent opening on the bottom of the roof overhang at the roof edge. In actuality, there is little or no ventilation because 2x4 blocking was installed to nail the plywood sheet edges. That blocking and the batt insulation effectively restricts air flow so that the volume of air below each outer 4x8 plywood sheet is not ventilated. Finally, the outer plywood surface is covered with a hypalon rubber membrane.

BUILDING INSPECTION FINDINGS

Mechanical-Electrical Building

This building was noted by the chief of maintenance to have had a major roof leak during the last winter with water dripping from an interior ceiling beam. No interior moisture generation sources were found upon inspection of the interior of the building. The building only housed equipment and had no occupants. Thus it was assumed that the cause of the leak was from water accumulating inside the roof cavity from an external leak rather than from condensation of internally-generated moisture.

The inside plywood surface of the ceiling was inspected for signs of water leakage or damage; none was noted. The surfaces appeared dry and there was no mold or water stains. However, in the region where a leak had previously existed, water was slowly dripping from a joint between the plywood and a laminated wood beam that supported the roof. Moisture content measurements were made in the vicinity of the leak; values ranged from 7 to 17 1/2% in the beam and from 12% to a maximum of 29% in the bottom surface of the plywood. Hence, some of the plywood was very wet. It appeared that water was accumulating above the lower plywood sheet. It had rained the previous evening. No openings were made into the roof cavity in this building.

The outside roof surface was carefully examined for leaks. No overt signs of leaks were found, except possibly for a few nail pops (heads raised). In walking around the roof a soft spot was noted, indicating possible decay underneath. The location was within the six foot wide overhang section. This also suggested the moisture source was external leakage rather than internally-generated moisture. The roof cavity was going to be opened up from the bottom side to inspect inside the cavity after the site visit. However, that inspection was not undertaken because the upper plywood surface was eventually removed and replaced. Other than some punkiness in the top surface of one roof joist, there was no noteworthy moisture damage found when the roof was replaced.

Hatchery Building

A preliminary walkthrough inspection of the building was made. Inside the hatchery room there were numerous fish water tanks that were open to the air; these represented a major interior source of moisture. The relative humidity was 64%. Numerous windows were open for ventilation. Generally speaking, it would be wise to cover those tanks if possible.

The exterior roof membrane surface was carefully inspected for leaks. In general, there were no overt signs of leaks, but close inspection indicated the hypalon rubber membrane had deteriorated since its original installation in the early 1970's. It contained numerous pinhole leaks in many places and in a few places small holes exposed the plywood beneath. In some of those latter places the plywood was delaminated and had a rippled top surface.

In one slightly low spot in the flat roof there was a large hole a few square feet in size (see Figure 3). A leak had been observed below inside the building. The hole apparently was caused by decay of the plywood. The top surface plywood that had been removed from the vicinity of the hole was clearly rotten (wood decay). The upper joists were in good condition except for a slight amount of decay on the top surface of the joist that was directly beneath the hole. That decay would not significantly reduce its structural integrity. The moisture content of the joist was very low. However, the moisture content of the lower plywood sheet was as high as 23%, which is relatively high. The upper plywood sheet moisture content was as low as 12% and generally was drier than the lower plywood. Presumably the decay was caused by moisture accumulation and subsequent wood decay.

It was decided to open a new hole about one square foot in area in the top plywood to inspect inside the roof cavity in an area about six feet away that felt solid and looked like it might be dry inside (see Figure 3). It was very humid inside. The bottom plywood had moisture contents up to 26% and looked dark and damp. The upper plywood was marked Group 1 exterior and along with the joists looked dry and had much lower moisture contents. No wood decay was noted. The insulation was in good condition, including the aluminum vapor retarder. There was no accumulation of moisture either on the lower plywood sheet above the vapor retarder or inside the insulation just above its aluminum foil vapor retarder facing.

In both hole cases it appeared that water had somehow leaked into the roof cavity, accumulated above the lower plywood panels, and caused localized high moisture content in the lower plywood as well as decay and overt structural damage in the first case. The fact that the bottom plywood was higher in moisture content than the upper plywood suggests that the moisture came from leakage rather than condensation. Condensation would normally occur at the coldest surface which was the outer plywood and in that case the moisture content should be higher in the upper plywood. That was not the case. Moreover, one should not expect an accumulation of moisture from condensation in the relatively warm June weather.

Given the high humidity inside the building, it is possible that moisture migrating out from inside the building could have condensed on the underside of the upper plywood and then dripped onto the bottom plywood during the winter. By the time the hole was cut in June (six feet away from the large hole), the sun could have dried the upper plywood sheet but not fully dried the lower. While possible, this explanation appears less likely. First of all, similar water leakage into the building was noted in the mechanical-electrical building. Yet it had no interior moisture sources whatsoever and low inside relative humidity by comparison. Of considerably greater importance is the fact that none of these buildings had any evidence of roof leaks or other moisture-related problems for over a dozen years prior to the leakage. Moreover, all the problems occurred in each of the buildings at about the same time. If condensation was dripping onto the lower plywood sheets and accumulating, it probably would have been observed as water leakage years ago. Finally, there is some evidence from residential roof research[1,2] that moisture migrating from inside a building is absorbed into wooden roof sheathing and stored long term. It often does not accumulate as condensed liquid on the surface, but rather is absorbed into the wood. Thus it does not drip off the surface, except in situations where there is a physical leak of water from outside.

Thus, based upon the above reasoning, it appears that moisture was leaking into the roof cavity from the outside. It is also noteworthy that the leak and the rotted hole occurred in a slightly low spot of the roof and that snow sits for long periods on the roof.

It should be mentioned that lack of time prevented making further openings from the outside of the roof. However, an additional opening was made from the inside. In an area just below the roof area where the leak and hole occurred, a loft area existed in the hatchery building. Thus it was easy to gain access to the underside of the roof. Close inspection in the loft area indicated numerous drip lines from previous leakage on the laminated beams; the water had leaked out from the joint between the lower plywood panel edges and the laminated beam (see Figure 4). In addition, rust was apparent on the drain pipes coming out of the roof cavity (see Figure 5).

Measurement was made of the moisture content of the beam and plywood about 7 1/2-8%, which is quite dry. However, near the leak signs there were a few locations where the ceiling plywood had moisture contents of greater than 30%, which is soaking wet. In the wettest location, a roughly one square foot hole was opened next to a beam by cutting the plywood with a circular saw (see Figure 5). As the cut was made, water trickled out of the roof cavity. After the hole was completely opened, the insulation was found to be soaking wet as was the bottom plywood. There was definite dry rot and some structural damage in places on both the plywood and the adjoining beam. However, the whole beam did not appear to be in jeopardy from the dry rot in that location. Lack of time prevented further openings from being made.

It seemed rather clear that water had leaked into the roof cavity in this location. The effect of that leakage was worsened by the fact that installation of 2x4 blocks as nailers for the top plywood panel edges had blocked off ventilation. Air circulation was thus reduced and natural drying impaired. The blockage can be seen in Figure 6 which shows the roof after the upper plywood surface was removed for inspection and subsequent repair of the roof. Even without the blockage the ventilation was minimal as only a one inch wide soffit ventilation screen was placed along the roof perimeter.

Food Preparation Building Freezer Room

Just prior to leaving at the end of the day, the freezer room was briefly inspected. There were no moisture generation sources inside the freezer room. Water was freezing on the ceiling, apparently after leaking into the freezer room from the roof. Light fixtures were torn loose at their mounts by heaving of the ceiling, as can be seen in Figure 7. These freezer room problems appeared to stem from roof leaks, just as in the case of the other two buildings inspected. Apparently a special coating was applied to the surface of this building in an attempt to temporarily fix the leaks. The flat roof was later replaced.

CONCLUSIONS AND EPILOGUE

As a result of a one day site visit and inspection of three Cole Rivers Hatchery buildings, it is clear that roof moisture damage existed. Evidence from visual inspections, roof openings, and wood moisture content measurements strongly suggested that the exterior hypalon rubber roof surface had deteriorated to such an extent that water was leaking into the roof cavity. The water accumulated, possibly because the roof ventilation system was impaired due to an error in the original roof construction, and caused leaks and high wood moisture contents in some locations and even some wood decay. That decay appears to have led to structural damage in the form of a hole in the roof of the hatchery building.

In all the buildings the roof moisture damage problems were noticed in the last year or two just prior to the visit and not previously. This appears to be tied to aging of the hypalon rubber roof surface and probably would have gotten worse had it been left unattended. That could have resulted in further major structural damage.

The recent history of leaks is important evidence that neither condensation nor lack of ventilation was a problem. The roof system worked satisfactorily for over a dozen years until serious roof leaks developed. No ventilation system would have prevented eventual damage from the roof leaks. The leaks would have had to be corrected to eliminate the problem.

It was thus recommended that the outer roof surface consisting of the hypalon membrane and the upper plywood surface be removed; that was subsequently done in all three buildings. The exterior of the roof cavity was inspected and minor repairs made. Then the roof level was raised to provide additional roof ventilation and a new similar flat roof was installed. Since flat roofs are always prone to leaks, a policy of regular inspection and recoating of the hypalon surface has been instigated to prevent future damage. Of additional importance is the need in the future for more careful design and inspection of such flat roofs to avoid blocking the ventilation. That is especially important with increased levels of insulation where blockage is more likely.

Finally, it is important to stress that all too often condensation is suggested as the cause of moisture damage in roofs. Prior to any inspection that was one suspected cause of the roof damage in this case. Yet undetected leaks or construction oversites or errors frequently are much more likely causes. One useful approach to determining the true cause and hence to deciding on a proper solution is to combine meticulous inspection of the problem area, including possibly inside the roof cavity made accessible by selective opening, with a review of the leak history. It is hoped that this case study will serve as a useful example to others.

REFERENCES

1. D.M. Burch, et al., "Experimental Validation of an Attic Condensation Model," ASHRAE Transactions, Part 2A, p. 59, 1984.

2. P. Cleary, and M. Sherman, "Seasonal Storage of Moisture in Roof Sheathing," Lawrence Berkeley Laboratory, Report No. LBL-17774, 1984.

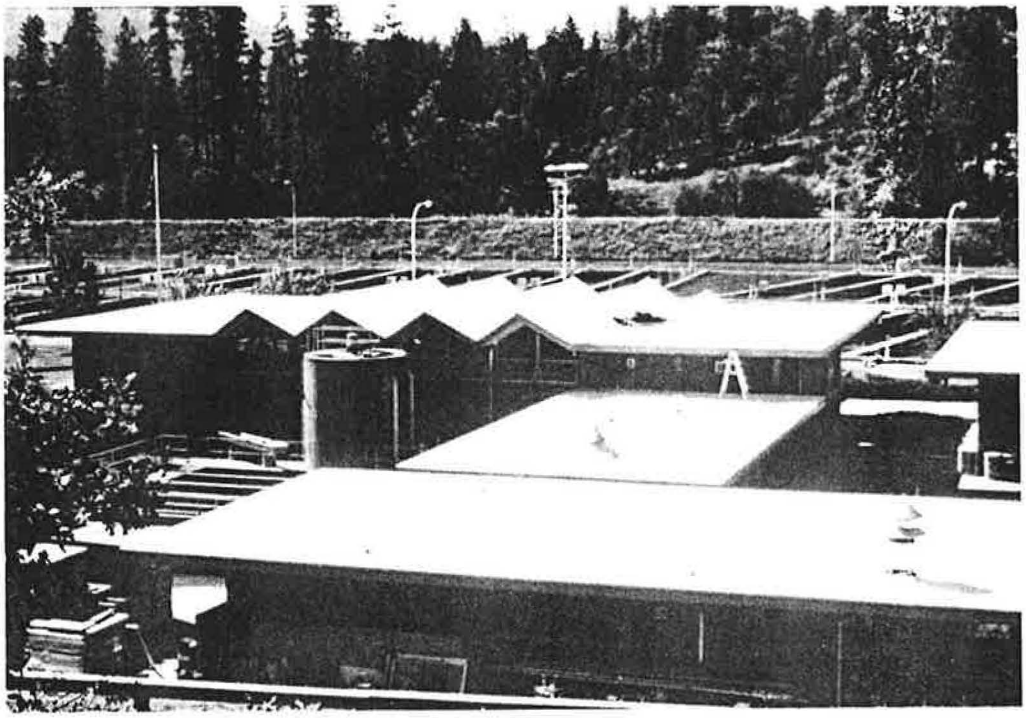

Fig. 1. Flat-roofed Cole Rivers Hatchery buildings.

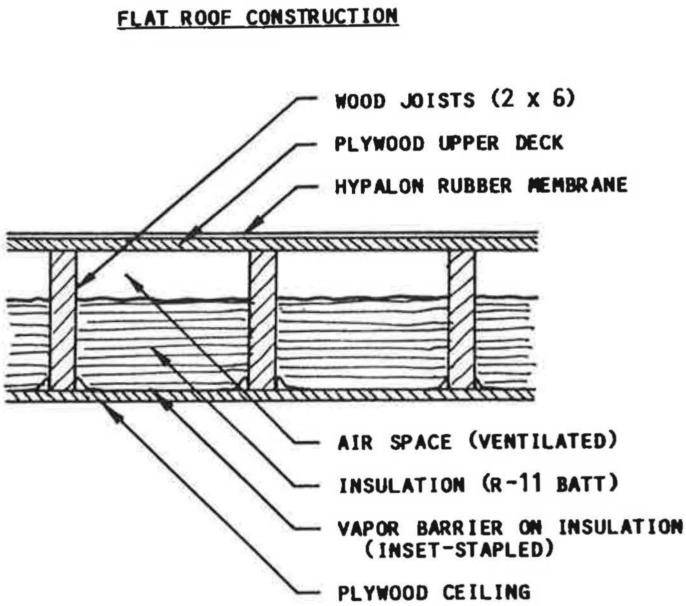

Fig. 2. Flat roof cross-section sketch.

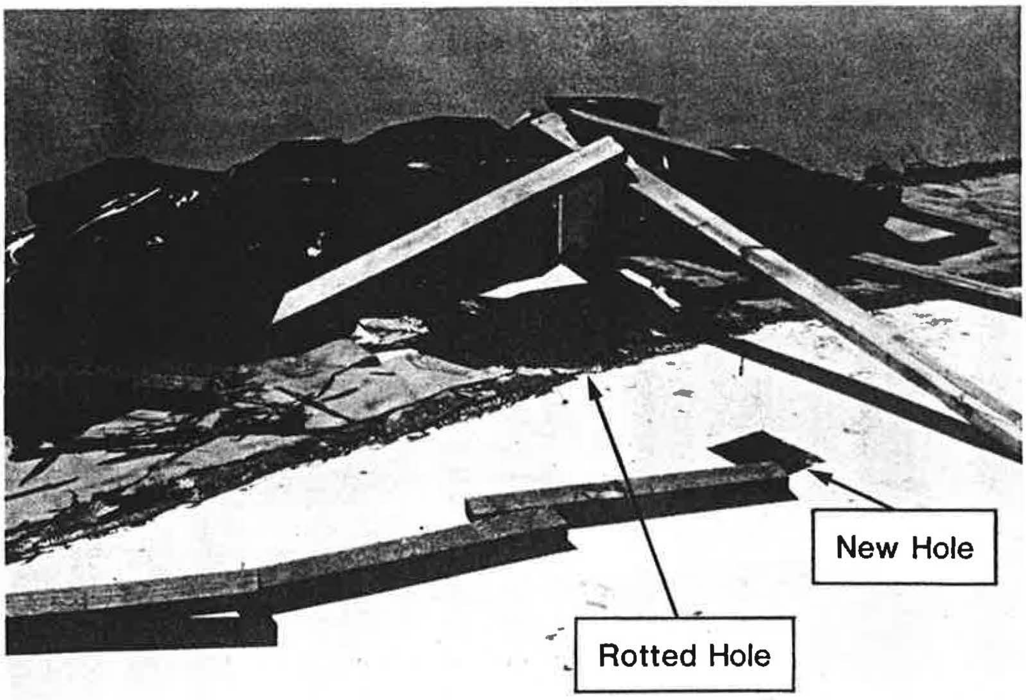

Fig. 3. Hole in the outer roof surface of the hatchery building.

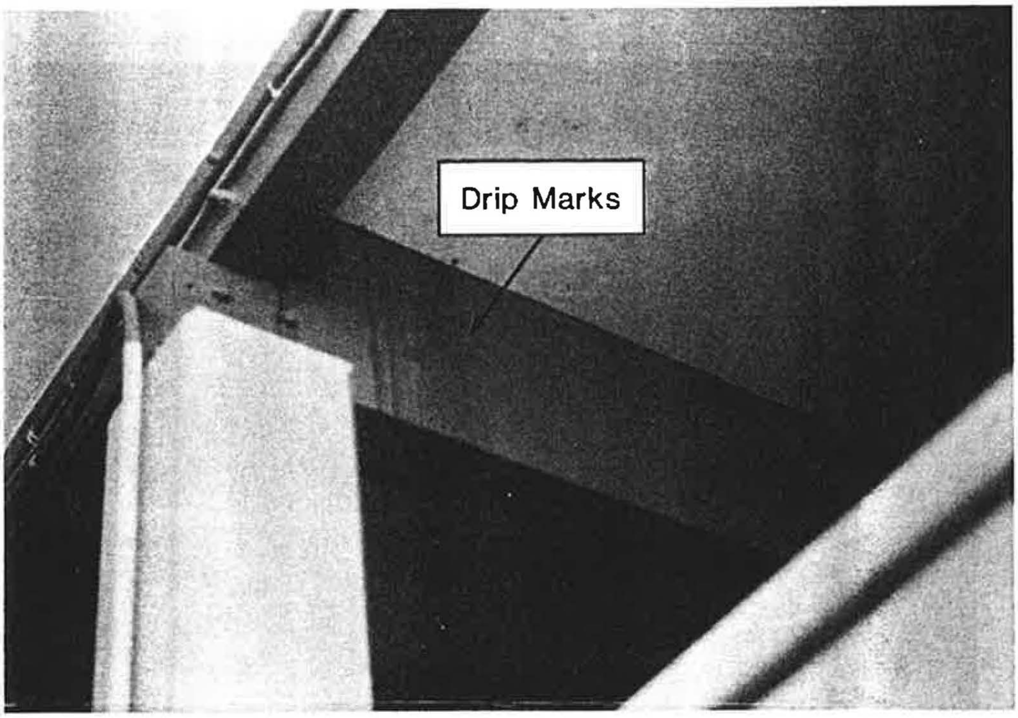

Fig. 4. Water leak drip marks on indoor ceiling laminated beam.

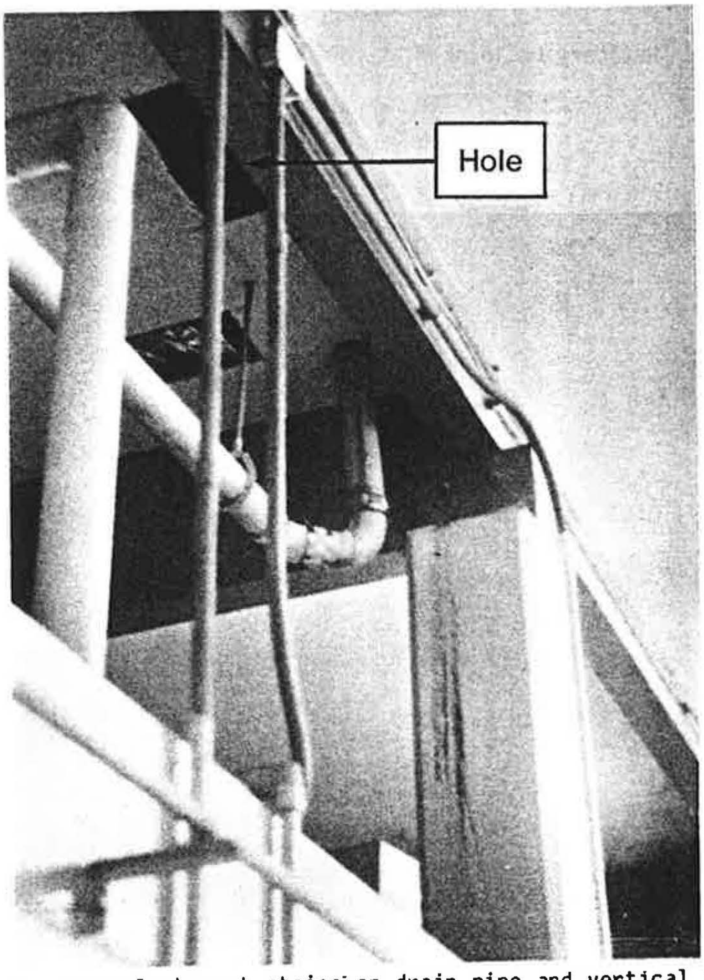

Fig. 5. Water leak rust stains on drain pipe and vertical post.

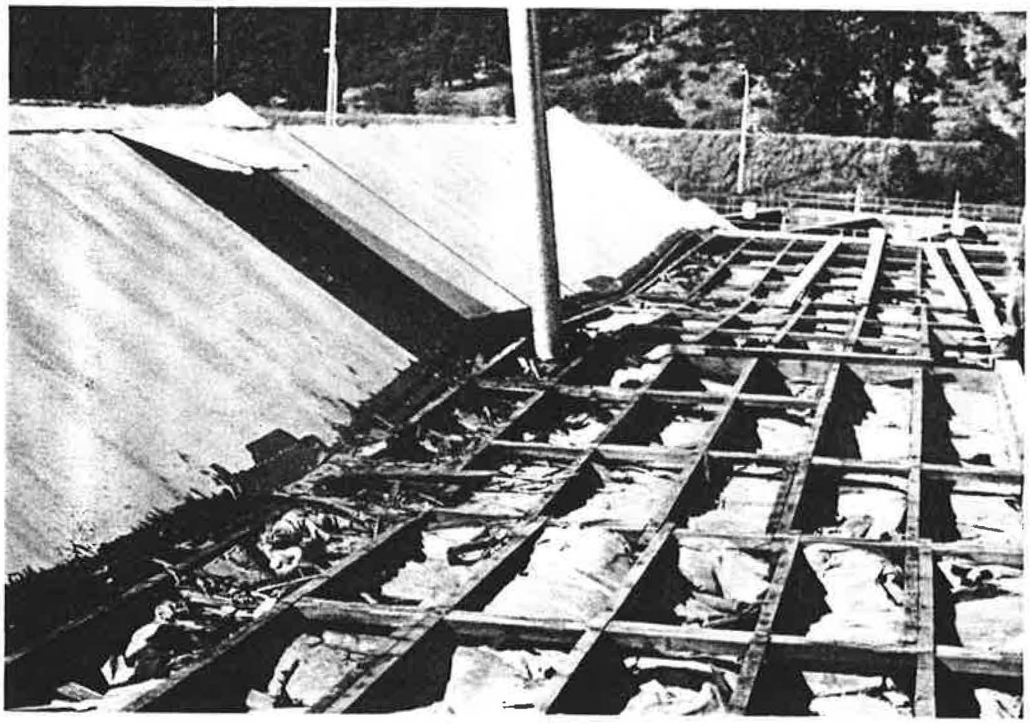

Fig. 6. Hatchery building flat roof with outer plywood surface removed.

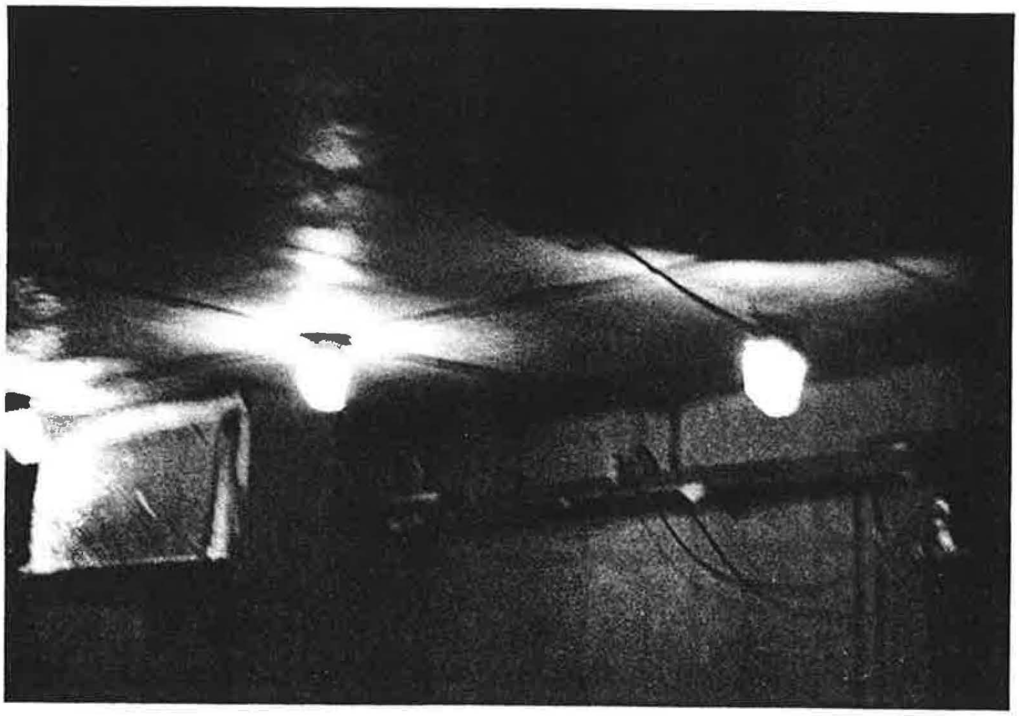

Fig. 7. Light fixtures torn loose in freezer room.