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Fire Performance of Interstitial Space Construction System

J. Randall Lawson

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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AREA

1 in^2 = 0.000645 square meter (m^2)
= 6.4516 square centimeters (cm^2)
1 ft^2 = 0.0929 square meter (m^2)

LENGTH

1 in = 0.0254 meter (m)
1 ft = 0.3048 meter (m)

MASS

1 lb = 0.453 kilogram (kg)

POWER

1 watt = 1 joule per second ($\frac{J}{s}$)

QUANTITY OF HEAT

1 Btu = 1055.87 joule (J)

TEMPERATURE

°F = 9/5 °C + 32

FIRE PERFORMANCE OF INTERSTITIAL SPACE CONSTRUCTION SYSTEMS

J. Randall Lawson

Abstract

Two unique walk-on deck construction systems were exposed to the standard NFPA 251 time-temperature fire exposure for periods up to two hours in order to evaluate their fire performance. A large scale steel structure was used in the test program to simulate construction systems found in the field. The structure consisted of two large functional floors separated by an interstitial space in which a walk-on deck was suspended from the top functional floor. One of the walk-on deck systems was constructed from lightweight concrete, and the second was built with poured gypsum. Critical components evaluated were the top functional floor, unprotected steel work in the interstitial space, the walk-on deck system, and protection for a heavy steel column located in the center of each test bay. Test data were compared with the fire endurance test requirements of NFPA 251. Computer predictions also were made using the FIRES-T3 model to determine its ability to accurately predict the construction systems performance.

The interstitial construction system achieved the design fire endurance.

Key words: Fire endurance; fire test; interstitial space; structural systems; floor systems; structural response; computer predictions.

1. INTRODUCTION

With the substantial growth in knowledge over the last one hundred years, architects and engineers have developed the ability to design and construct buildings more complex and larger than many people thought possible. It is not uncommon to find that these structures contain hundreds of thousands of square feet in area and cost hundreds of millions of dollars when they are completed. In order to protect these buildings and their occupants from fire, the designers must provide a safe yet economical approach to fire protection design. With many of these complex designs, small variations can lead to unsafe conditions or substantial increases in cost. This is a difficult task since fire safety cannot always be easily determined, while cost savings are easily shown on the project's budget estimate. Currently, the only recognized means for evaluating a building system is to submit it to a standard fire test and observe its performance.

The project described in this report was carried out to address the need for measuring fire performance of two recently designed interstitial space construction systems proposed for installation in Veterans Administration medical facilities. These construction systems consist of an interstitial space (separating two functional floors) created by the installation of suspended walk-on decks and were evaluated using the National Fire Protection Association (NFPA) 251 standard, Standard Methods of Fire Tests of Building

Construction and Materials [1]*. Several design questions were evaluated in this investigation:

1. Would the new designs provide a two hour fire rating (by NFPA 251) for the functional floor above each interstitial space design?

2. Does the firestopping around the duct penetrations in the walk-on deck provide adequate protection to prevent fire spread into the interstitial space?

3. Is the fire protection provided by the interstitial space walk-on deck system sufficient to permit elimination of fireproofing on structural steel members in the interstitial space?

4. Can the fireproofing on the purlins supporting the walk-on deck be omitted and still provide appropriate protection to the interstitial space and functional floor above?

In addition to the above testing, a computer model was also used in an attempt to predict the heat transfer through one of the walk-on deck systems. The FIRES-T3 computer model [2], developed at the University of California, was used to provide this evaluation. The results from the computer model are compared with temperature data recorded during the fire tests.

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*Figures in brackets indicate literature references at the end of this report.

2. TEST METHOD AND SUPPORTING STRUCTURE

The test method used for evaluating the building systems in this project was NFPA 251-79. A special two story steel test structure was modified to provide a large scale test facility for this project as shown in figure 1. Briefly, the referenced method requires that a building system test specimen be constructed in a way that is representative of that found on an actual construction site. Since the building systems evaluated in this study were primarily floor systems, the standard requires that no less than 180 ft^2 of the assembly be exposed to the fire environment. Details on the tested construction systems are found in sections 3 and 6. The fire test exposes a specimen to a standard time-temperature fire environment throughout a specified length of time. Figure 2 shows the standard time-temperature curve. This exposure is not designed to represent all fire conditions but does provide a relative measure of fire performance for comparable assemblies under the same specified fire conditions.

The conditions for acceptance of these building systems are found in several different sections of the test standard. The acceptance conditions relating to temperature recorded on the functional floor are found in sections 10-5 and 10-6 of the standard. Since the functional floor was restrained by a steel angle around its perimeter, section 10-5(b) applies. This states that heat transmission through the specimen during the classification period shall not raise the average temperature on its unexposed surface more than 250°F above its initial temperature. The acceptance conditions for the structural steel members supporting the functional floor comes from section 10-6(c). This specifies that the structural steel members shall not exceed 1300°F at any single location during the classification period nor shall the average temperature recorded by four prescribed thermocouples at any section have exceeded 1100°F during the same period. The specification for applying a load to the functional floor system was not followed in any of the four tests. The sponsor requested that the surface of the walk-on deck not be loaded during the tests. The Veterans Administration stated that no live loads would be allowed on the walk-on decks except for an occasional inspector or workman. This variation from test standard was adopted because it was recognized that should a failure occur with the walk-on deck the unprotected steel in the interstitial space would likely reach a failure point before a load or cotton waste ignition failure would occur on the functional floor. The budget for this test program also did not allow for a major load failure with the functional floor since this would seriously damage the test structure. However, design loads were applied to the purlins supporting the walk-on decks in two of the three tests in this project. See each test description for details.

Another structural component of importance was the W14x61 steel column located in the center of each test bay. This is shown in figures 1, 3, and 4. Acceptance conditions from the NFPA standard, section 9-5, state that heat transmission through fire protection enclosing the column shall not raise the average of recorded steel temperatures at any one of four levels above 1000°F. In addition, temperature rise at any one of the measured points shall not exceed 1200°F. Load failures were not considered in these tests because the design load was not applied to any of the columns tested.

2.1 Test Structure

A unique structure built at NBS for an earlier fire study [3] was modified to meet the needs of this program. The test structure was originally designed to represent the mid-height of a twenty story steel frame building. Drawings of the structure as used in this test program are shown in figures 1, 3, and 5. The structure consists of three different levels. The ground level, figures 3 and 4, served as the fire compartment and represented a patient floor on fire. The second level, figure 5, consisted of the suspended walk-on deck system which formed the lower part of the interstitial space enclosure. The top level, figure 6, served as a functional floor which represents a patient floor in a medical facility. The slab for this floor was poured on an existing 20 gage galvanized steel deck.

Only two of the four bays were used for testing. These bays are the ones shown with the burner walls and chimneys in figure 3. The walk-on deck surface area exposed to the fire compartment was 320 ft^2, which is almost twice the minimum area required by the test method. The W14x61 steel columns located in the center of each test bay were required by the VA test design. See figure 4. This was done in order to better simulate the actual finished construction system to be used in the field. The short concrete block walls resting on the mid-height beams in figure 1 were used to provide the required vertical spacing for the interstitial space. The wall construction enclosing the interstitial space is described in section 2.4. All openings around the test assemblies and interstitial space walls were packed with mineral fiber firestopping to prevent leakage of hot gases.

2.2 Furnace Design

The fire compartments in these tests were located on the ground level of the structure. The frame for the walls enclosing the compartments was constructed with light gage steel studs. The enclosure was completed by fastening 20 gage steel sheet metal to the interior side of the studs. In order to protect the metal fire compartment walls from intense heat produced by the burner, a high temperature ceramic fiber blanket was fastened to all exposed wall surfaces. All structural steel supporting the test structure and exposed to the fire compartment was coated with a minimum 2 inch thickness of spray-on cementitious fireproofing. The floor of the fire compartment was earth; building sand was used to fill any openings found at ground level.

The fire exposure for each test was supplied by a single 15 million Btu/h propane gas burner. Test exposure temperatures were monitored by 10 furnace thermocouples located one foot below the bottom surface of the walk-on deck. Two additional furnace thermocouples were located in the interstitial space one foot below the bottom surface of the functional floor. These thermocouples were to be used for fire exposure control if the walk-on deck experienced a massive failure and allowed the hot gases to rise into the interstitial space.

2.3 General Description of Test Assemblies

Each of the three test assemblies evaluated in this study had the following construction details in common: See figures 1 and 3-6. (1) the fire compartments located at ground level were all constructed as described in section 2.1 and 2.2, (2) the W14x61 steel columns, supported on individual footings located in the center of each test bay, extended through the walk-on decks and were fastened to the W12x22 beams supporting the center of the functional floor above the interstitial space, (3) these columns were protected with a two hour type-x gypsum board system in the fire compartments, see figure 7. (The gypsum board fire protection systems were completely rebuilt after each fire test.) (4) there was no fire protection applied to the steel column where it was exposed to the interstitial space test environment, and (5) the walk-on decks tested were supported on purlins fabricated from hot rolled structural steel and were suspended by 6 ft-2 in long, 0.625 inch diameter steel hanger rods. Each of the eight steel rods was screwed into individual 0.625 inch tapped steel studs that were welded to the bottom of the W12x22 steel beams supporting the functional floor above. All welds were made by a certified welder. These vertical hanging rods were fastened on the other end to purlins which supported the walk-on decks. Pieces of steel tubing measuring 4 x 4 x 1/4 inch were cut into 3 inch long sections and were welded to the top flange of the purlins. These pieces of tube were located to match the suspension rod positions. The tubes were welded into place by a certified welder at points shown in figure 8. A 0.75 inch hole was drilled through the top of each tube section to allow for fastening the rods. The purlins were suspended by inserting the rods through the drilled holes and placing 3 x 3 x 5/8 inch square steel washers and 0.625 inch nuts on the rods. The nuts were tightened until each purlin was completely suspended 0.50 inch above the masonry extension wall at the fire compartment's top, figure 1. The center purlins ("B") in figure 5 were also attached to the W14x61 steel column. They were fastened to the column by clip angle shear connections using two high-strength bolts through the purlin web and two high-strength bolts through each clip angle and the steel column. The suspended purlins provided support for each of the walk-on deck test assemblies.

The functional floor located above the interstitial space was constructed using 2 inch deep 20 gage galvanized steel deck. A 3 inch fill of normal weight (150 lb/ft^3) Portland cement concrete with 4000 lb/in^2 strength was poured on the steel deck. Reinforcing mesh made of 19 gage galvanized steel wire twisted to form 2 inch hexagons with an additional 16 gage galvanized longitudinal wire placed at every 3 inch interval of its width was embedded in the poured concrete. The perimeter of this slab was held in place by 3 x 3 x 3/8 inch steel angles welded to the W12x22 steel perimeter beams.

The functional floor was poured on June 6, 1983, and the first test was conducted 71 days later. The last fire test was conducted 169 days after the floor was poured. The floor, which made up the structure's top level, was covered on rainy days and was uncovered on fair days to promote drying. Even with these precautions, the middepth relative humidity measurements made with a relative humidity meter before testing were typically 97 percent.

2.4 Dummy Air Conditioning Duct Construction and Installation

Two 10 x 10 inch air conditioning ducts were located in the interstitial space formed by each fire test assembly. The ducts penetrated the walk-on decks at holes made before the decks were poured. Details of duct construction are shown in figure 9. Locations for duct penetrations are shown in figure 5.

The longer duct represented the supply duct in each fire test and the shorter duct represented the return air. No flow passed through these ducts during the fire tests. Sheet metal plugs were used to seal the duct's ends that penetrated the interstitial space's outside wall. The duct ends that extended through the walk-on decks and into the fire compartment had commercially manufactured sheet metal diffusers attached. The louvers on these were left open during testing. The supply ducts were covered with 1.5 inch thick glass fiber blanket insulation meeting Federal Specification HH-I-558B[4]. This insulation was Form B, flexible blanket, Type 1, Class 6 B3, 1 pcf density, with a k factor of 0.31 Btu-in/h-°F and a temperature rating up to 350°F. The insulation was installed using normal field practices which included wire tying and taping with duct tape.

After the ducts were positioned and wrapping was completed on the supply duct, mineral fiber fire safing was used to fill the remaining space around the walk-on deck duct penetration. The mineral fiber safing used was 4 inches thick and met the requirements of Federal Specification HH-I-558B, Form A, 4 pcf density, with a k factor of 0.24 Btu-in-/h-°F, and a melt point of 2000°F. The mineral wool safing was installed to completely encircle the duct and seal the penetration. It extended 6 inches above and below the walk-on deck. The safing was wire tied into place with 16 gage tie wire.

2.5 Interstitial Space Enclosure

A specially designed gypsum wallboard system was constructed to enclose the volume comprising the interstitial space. The system was designed to provide protection from weather on the outside and to provide fire protection to the metal stud system supporting the wall on the inside. The system was also designed to resist leakage of hot gases in the event that a walk-on deck experienced a significant failure. A detail of this wall system is shown in figure 10. These walls were penetrated by two dummy air conditioning ducts during each test as seen in figure 11.

2.6 General Instrumentation

2.6.1 Center Column Instrumentation

A. Fire Compartment

A total of twenty, 24 gage, type K thermocouples were used on each of the W14x61 steel columns to measure performance of the steel and two hour gypsum board systems during each fire test. The placement of these thermocouples is shown in figure 12. These thermocouples were positioned to meet the requirements in NFPA 251. Thermocouples attached to the steel column were placed into 0.062 inch diameter drill holes and peened into place. Thermocouples on the gypsum board were mounted in contact with the respective surface and were held in place by staples.

B. Interstitial Space

Six 24 gage, type K thermocouples were attached to each of the W14x61 steel columns in the interstitial space, figure 12. Each of these thermocouples was peened into the column surface using the procedure stated above.

2.6.2 Center Beam Supporting the Functional Floor

A total of 24 stainless steel sheathed type K thermocouples with an outside diameter of 0.125 inch were attached to the W12x22 steel beam at six different locations, figure 13. These thermocouples were peened into 0.187 inch holes drilled into the steel surfaces. The thermocouples were positioned to meet the requirements of the NFPA 251 fire test procedure.

2.6.3 Steel Deck Supporting the Functional Floor

Eight stainless steel sheathed type K thermocouples, 0.125 inch outside diameter, were silver soldered to the steel deck at locations shown in figure 14. Leads from these thermocouples were bent vertical to extend above concrete poured on the deck.

2.6.4 Functional Floor Surface Instrumentation

Nine 24 gage, type K thermocouples were positioned on the surface of each functional floor tested. These thermocouples were located as shown in figure 15. These measurement locations are as specified in NFPA 251. Each thermocouple was covered with a 6 inch square, 0.375 inch thick refractory fiber pad that meets the requirements of ASTM E 119-83, Standard Methods of Fire Tests of Building Construction and Materials[5].

2.6.5 Deflection Instrumentation

Three deflection gauges were used to record movement of each of the suspended purlins. The deflection gauges were mounted on frames located above the functional floor, and the deflection wires went through 0.50 inch holes drilled through the functional floor. The deflection gauge wire was held in place on the purlin's flange by a metal weight. These gauges measured the deflection at the center of the span between the suspension rods, figure 16. In tests where load was applied to the purlins, the deflection gauge weights were positioned on top of sand filled plywood boxes. This can be seen in figure 17.

2.6.6 Interstitial Space Air Temperature

A thermocouple tree consisting of seven, 24 gage, type K thermocouples was located next to the center column in each test. The thermocouples were spaced at one foot intervals between the bottom side of the functional floor and the walk-on deck's top surface.

2.6.7 Dummy Air Conditioning Duct Temperatures

Three type K, 24 gage thermocouples were located on each duct, figure 18. On the supply duct, one thermocouple was centrally located inside the duct to measure air temperature, one thermocouple was attached to the duct's surface, and the third was attached to the outside surface of thermal insulation which was wrapped around the duct. The thermocouple fastened to the insulation was located directly above the thermocouple attached to the duct's surface. For the return duct, one thermocouple was centrally located inside the duct and two were attached to the duct's surface (there was no insulation on this duct).

3. DESCRIPTION OF LIGHTWEIGHT CONCRETE WALK-ON DECK SYSTEMS

The lightweight concrete walk-on deck system was used in tests 1, 2, and 2A. The walk-on deck was built on the suspended W6x9 steel purlins. Construction details for the deck are shown in figure 19. The 1.5 inch deep type B steel deck was attached to purlins with 0.50 inch diameter puddle welds using welding washers. The welds were made at every other flute of the metal deck in contact with the lower flange of the purlin. Welds were also made every 36 inches along each side deck seam to fasten the decking together. After the steel deck was laid, two 15 inch square holes were cut through it, and they were boxed in with wood forms to provide penetrations for the air conditioning ducts. This can be seen in figure 4. It should be noted that the metal deck around the air conditioning openings exhibit weakness after the openings are cut. This weakness is significant if a deck joint passes through the opening. Deck welds may be broken, and the deck will sag if supports are not put in to make the area rigid when the concrete is poured. During test assembly construction, temporary T-braces were used to support the steel deck from ground level. Before any further construction work was done, a group of thermocouples was attached to the deck and purlins, as described in section 3.1. Reinforcing mesh made of 19 gage galvanized steel wire twisted to form 2 inch hexagons with an additional 16 gage galvanized longitudinal wire placed at 3 inch intervals along its width was laid on top of the steel deck. Wood forms were placed around the deck perimeter. Lightweight insulating concrete containing vermiculite aggregate, with a density of 27 to 35 pcf, was then poured. The wire mesh was worked into the concrete mix so its finished level was at approximately half the concrete thickness. Total thickness of the finished floor was 5 inches. After the concrete set and initial drying was complete, forms around the deck and air conditioning penetrations were removed. The lightweight concrete walk-on decks tested in this project were poured on June 13, 1983. The first walk-on deck system was tested 64 days after it was poured, and the second walk-on deck system was tested after 147 days. These deck systems were protected from the weather throughout the period before testing. Attempts were made to heat and ventilate the decks to reduce moisture content. This had little affect on the deck systems since the environmental relative humidity was generally high during the curing period. A relative humidity of 95 percent was measured at middepth in both walk-on decks just before each was tested. Relative humidity measurements in the walk-on decks were made using an electric hygrometer, model 15-3000, manufactured by Hygrodynamics, Inc.* This information led to the fire exposure period being extended beyond the planned two hours. It was decided to conduct the tests until some observed failure occurred.

Just after the lightweight concrete decks were poured, a local fireproofing contractor spray applied a 1.5 inch thick coat of fireproofing on the lower flange of the W6x9 steel purlins in test bay #1. The fireproofing

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*Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

specifications are shown in table 1. Before the fireproofing was applied, the purlins were cleaned to remove surface contaminants and rust. The fireproofing completely covered the lower flange and was feathered to about 6 inches either side on the metal deck. Figure 20 illustrates the spray applied fireproofing. Initially no fireproofing was applied to the purlins in test bay #2. However, after the first fire test, it was decided that a different fireproofing should be evaluated. The second material shown in table 1 was applied to the purlins in test bay #2 after some other modifications were made. In addition to this change in fireproofing, it was decided to determine if woven wire mesh would improve bonding of fireproofing to the purlins. The same wire mesh described earlier in this section was used to cover the lower flanges on two purlins. On purlin "A" (see figure 5), wire mesh was wrapped around the lower flange and 22 gage steel sheet metal clips were slipped over the wire and flange to secure it. On purlin "B", the wire mesh was simply bent over the purlin flange to secure it. No wire mesh was attached to the purlin "C", which crosses quadrants III and IV. After the wire mesh was hung, fireproofing was spray applied to all three purlins.

3.1 Special Instrumentation for Lightweight Concrete Walk-On Deck System

Since the walk-on deck acted as membrane protection for the bare steel in the interstitial space from the fire environment, special efforts were made to accurately document the thermal response of each component in the system. Data obtained from these measurements provided the data necessary for analyzing the interstitial construction system's response to the fire tests. The measurements were also used to compare performance with predictions made by the FIRES-T3 [2] computer model for the fire response of structures, as described in section 9.

Thirty stainless steel sheathed, type K thermocouples with an outside jacket diameter of 0.125 inch were positioned in the lightweight concrete deck as shown in figures 21 and 22. An additional 16 thermocouples of the same type were attached to each of the full length purlins. The thermocouples were attached by placing them into shallow 0.187 inch drill holes and peening them in until tight. This arrangement can be seen in figure 22. One more thermocouple of the same type was fastened, using the same technique, to one of the 4 x 4 x 1/4 inch steel tubes used to couple the purlin to the suspension rod. This thermocouple was attached to the tube located in the center of purlin "C". A single 24 gauge, type K thermocouple was located halfway up the suspension rod that extended through the same steel tube. The thermocouple was wire tied to the suspension rod, and the junction was held on the surface with high temperature tape.

4. TESTING OF LIGHTWEIGHT CONCRETE WALK-ON DECK SYSTEMS

Originally, two fire tests were to be conducted on the lightweight concrete walk-on deck systems. One test was to be conducted with the walk-on deck unloaded and fireproofing applied to the purlin flanges exposed to the furnace compartment. A second identical test was to be conducted but with no fire protection applied to the fire exposed purlin flanges. This initial test plan was altered after the first test because of problems experienced with the performance of the fireproofing protecting the walk-on deck purlins. More details are given in sections 5.1.1 through 5.1.3. As a result of the initial test results and discussions with the sponsor, it was decided to try a different fire rated fireproofing material and to apply a load of 90 lbs/lin ft to each of the suspended purlins. The box containers shown in figure 17 are filled with building sand. Another change made after the first test was the installation of a 0.625 inch nut and standard washer on each suspension rod above the tube brackets. These nuts and washers were tightened against the brackets after the bottom nuts and heavy washers were used to suspend the purlins.

The second test assembly, which had been built at the same time as the first, occupied the second test bay; this test bay was constructed to duplicate test bay #1. However, it was found during the second test that heat loss was much greater in bay two than experienced in bay one. This finding lead to the second test being stopped at 1 hour 30 minutes into the test because of excessive fuel usage. A careful study of the two test bays revealed only one slight difference in construction. A temporary lintel had been placed at the stack entrance in test bay one during a project preceeding this one. Not surprisingly, the lintel apparently reduced the hot gas flow from the fire compartment and significantly altered fuel usage as compared to the new second test bay. An identical lintel was built and installed in test bay #2.

Analysis of surface damage to the walk-on deck, fireproofing on the purlins, and other structural elements after the second fire test showed little damage. The metal decking and lightweight concrete floor showed no openings. All fireproofing remained on the purlins. The only major damage was noted on the two hour gypsum board system protecting the test column.

Additional details describing this test are found in sections 5.2.1 through 5.2.3. Based on this information and the need to fully test this walk-on deck assembly, a decision was made, with the sponsor's concurrence, to conduct another complete two hour fire test on this same assembly. The entire gypsum board fire protection system was removed from the center column and a completely new system of the same design was constructed. After the above modifications were made to the test assembly, the walk-on deck system was successfully tested for the required two hours. Test results for this fire exposure are located in sections 5.3.1 through 5.3.3.

5. TEST RESULTS FOR LIGHTWEIGHT CONCRETE WALK-ON DECK SYSTEM

5.1 Test 1 Fire Endurance for Lightweight Concrete Walk-on Deck System

The record of the average furnace temperature as compared to the standard time-temperature curve is shown in figure 23. The record shows a test duration of 2 hours, 15 minutes.

5.1.1 Test Observations, Test 1

Time, hr:min:sec	
	Test begins at 8:20 a.m., 8/16/83
00:00:00	Ignition
00:01:49	Burner adjustment.

00:02:14	Paper burning off of gypsum board protecting the column and pier in the furnace compartment.
00:03:24	Steam is coming out around penetration of return duct in the interstitial space.
00:04:25	Steam is forming around the base of the column in the interstitial space.
00:05:00	Looking through an observation post into the interstitial space, a small amount of steam is showing around the purlins. Visibility in the interstitial space is good.
00:10:25	Steam has reduced visibility in the interstitial space to zero.
00:12:00	Steam is coming out of small openings along the walls enclosing the interstitial space.
00:12:30	No heating noted at the top functional floor level.
00:14:00	Fireproofing fell from a portion of the purlin in quadrant III and the center purlin between quadrants I and IV.
00:14:37	Deck is showing buckling in the furnace compartment.

00:24:55	Steel decking is showing signs of oxidation and metal corner beads on column fire protection in the furnace chamber are starting to warp.
00:34:45	The joint is opening at the top of the pier on the fire side.
00:42:30	Gypsum board is still in place around the column and pier in the furnace compartment.
00:50:00	Moisture collecting on structure outside of interstitial space as a result of condensing steam.
00:55:44	Gypsum board around column and pier is showing cracks.
01:00:00	Steel flooring is bending and may have sagged as much as two inches. Fireproofing is mostly still in place on the purlins. Gypsum board corner joints on the column and pier are open slightly up to about 0.25 inch.
01:04:12	Gypsum board around the pier is showing marked signs of calcination.
01:10:45	Purlin in quadrant III appears to be sagging.
01:15:00	Deck between the center purlin and both adjacent purlins is sagging about two inches.

01:17:45 Fire protection around the column is showing marked signs of calcination. First layer of gypsum board around the pier is starting to fall off.

01:21:00 Fireproofing on the center purlin, between quadrants II and III, has fallen off and gypsum board joints around the column have opened up to about 0.5 to 1 inch.

01:36:09 Two layers of gypsum board protecting the pier have fallen off on the fire side.

01:36:50 Steam is still coming from small openings in the walls around the interstitial space.

01:48:00 Gypsum board around the column is buckling and joints are continuing to open.

01:53:55 The first layer of gypsum board on the column has fallen off, and the bottom layer of gypsum board is still secure.

02:00:00 The bottom layer of gypsum board on the column is still in place but is cracked with the joints at the corners open about 1 inch.

02:16:00 Bottom layer of gypsum board on the column, East side, fell off.

02:17:00 Test is terminated.

5.1.2 Post Test Observations, Test 1

1. Most of the inside layer of gypsum board is still in place around the center column. The metal studs supporting the gypsum board on the column are still in place, figure 24.

2. The pier has spalled on the side exposed to the furnace burner. One piece of concrete approximately 2 inches deep and 6 to 8 inches in diameter has broken away from the pier.

3. The walk-on deck between the purlins has sagged. The metal flooring has dropped away from the concrete floor at one place near the return duct and is sagging approximately one foot below the bottom of the current floor level, figure 24.

4. About 75 to 85 percent of the fireproofing on all of the purlins has dropped off. Only three spots are left where fireproofing remains.

5. All of the firestop material is still in place at the duct penetrations.

6. No signs of burning were noted in the interstitial space.

5.1.3 Discussion of Test Results, Test 1

The critical temperature measurements mentioned in section 2, from NFPA 251, relate to the performance of the functional floor, unprotected steel in the interstitial space, and the W14x61 steel column. As can be seen in figures 25 to 29, all surface temperatures were well below the allowable 250°F temperature rise failure point at the test's end. As shown in figure 30, the functional floor's steel deck temperatures only approached 200°F. Figures 31 to 34 exhibit the temperature rise experienced with the unprotected structural steel elements in the interstitial space. These indicate relatively uniform distribution of heat in the interstitial space. Again, the temperatures on these structural elements were well below the failure temperatures at the maximum exposure time. These data show that the lightweight concrete walk-on deck system acted to provide significant protection to the steelwork in the interstitial space from the high temperature fire.

The protected W14x61 column in the fire compartment also successfully passed the NPFA 251 two hour fire test criteria with a maximum single point temperature of 1002°F. The column temperature did reach a failure point during the extended test phase at nearly 2 hours 15 minutes. This can be seen in figures 33 to 38.

Other test data demonstrated the significant effect associated with the loss of fireproofing protecting the walk-on deck purlins. Figures 39 to 42 show the temperature history for these purlins. The purlin sections in quadrants I and III showed early temperature failures. These failures occurred at 40 and 26 minutes, respectively, resulting from fireproofing falling off of the purlins. On the purlins where fireproofing remained in place throughout most of the test, temperatures remained below the critical temperature of 1300°F.

Figures 43 to 46 shows a comparison of walk-on deck temperatures. The high temperatures noted in figure 44 resulted from a crack developing in the walk-on deck near the measurement location. Temperatures were high enough to easily ignite cotton waste, as referenced in NFPA 251. Figures 45 and 46 show temperature rise data for a floor area that did not exhibit major cracking. In this case the surface temperatures stayed below 250°F.

As stated earlier, temperature measurements were also made on two suspension rods and a steel tube bracket. Temperature plots for these construction elements are shown in figure 47. Each of these components performed well with temperatures remaining below 400°F. Figure 48 shows representative temperature data for the dummy air conditioning ducts. The large difference in surface temperatures between the supply and return ducts is attributed to the fact that the supply duct was wrapped with insulation, and the return duct was not. Figure 49 shows selected air temperature data in the interstitial space. Data obtained on deflections of the walk-on deck purlins are presented in figure 50. These deflection plots show that the purlins moved in various directions throughout the test. These data do not appear to accurately reflect the observed permanent upward bend experienced with each of the totally suspended purlins. Figure 51 illustrates an example of the 3 inch upward permanent set of purlin "C". The picture shows the suspension bracket. This unusual movement of the purlins has been studied, but no firm conclusions have been drawn. The behavior of these purlins resulted in questions concerning their performance while carrying the specified design load of 90 lbs/lin. ft. Plans were made to test the remaining walk-on deck systems with their designed load.

5.2 Test 2 Fire Endurance for Lightweight Concrete Walk-on Deck System

A record of the average furnace temperature is presented in figure 52. This test was terminated at 1 hour 30 minutes into the test. This termination was not related to any failure of the construction assemblies under test. It resulted from the excessive heat losses from the fire compartment described in section 4.

5.2.1 Test Observations, Test 2

Time, hr:min:sec	
	Test begins at 1:47 p.m., 11/7/83.
00:00:00	Ignition
00:00:54	Gypsum board paper ignited on the column.
00:03:10	Propane burner output reduce. Flame is not currently impinging on the pier or the column.
00:04:00	All fireproofing is still in place on the purlins.

00:05:54 Visibility in the interstitial space is still good. Steam was evident in the enclosed space.

00:06:45 All gypsum board paper on the burner side of the column has burned off.

00:11:25 Steam has reduced visibility in the interstitial space to zero.

00:13:15 All fireproofing is still in place on the purlins.

00:15:15 The metal deck exposed to the furnace is showing some buckling.

00:25:00 The steel deck joints have separated at two locations. The joint on the west side of the column above the burner has opened up approximately 0.5 inch. The second joint to the east of the column has also opened about 0.5 inch.

00:35:15 The steel corner head on the gypsum board protecting the column has started to warp, and the first layer of gypsum board is showing some cracks.

00:47:00 Gypsum board joints continuing to open on pier and column protection.

01:00:00	Steel flooring is exhibiting sag of about 1 to 1-1/2 inches between the purlins.
01:05:10	It has been noted that the fuel consumption rate is about 2 times that of the first test.
01:09:45	All fireproofing is still on the purlins and the joints of the gypsum board have opened on the first layer to about 0.5 inches.
01:15:00	Fuel consumption rate is still high even though attempts have been made to reduce consumption by changing the combustion mixture.
01:16:40	The first two layers of gypsum board protecting the pier have fallen off where the flame is impinging on the pier.
01:25:10	Fuel consumption is still high after more attempts to reduce fuel needs.
01:30:30	The burner has run out of fuel, and the test has been stopped.

5.2.2 Post Test Observations, Test 2

1. Three layers of gypsum board are still in place around the pier.

2. All fireproofing is still in place on the three purlins, but it shows some cracking, see figure 53.

3. The steel floor deck shows a sag of about 1 to 2 inches between the purlins, see figure 53.

4. One layer of gypsum board on the column is still in place.

5. The purlins appear to be straight.

5.2.3 Discussion of Test Results, Test 2

Data plots for the 1.5 hour exposure period are presented for this test so that comparisons can be made with test 1 and test 2A. Test 2A represents the retesting of the original assembly exposed to the fire environment in test 2, and its results are presented in section 5.3

Data representative of the functional floor surface temperatures recorded during test 2 are shown in figures 54 to 58. The surface temperature from this test never exceeded 77°F. This was also well below the failure point of 250°F. The cooler surface temperatures in this test reflected the cooler weather experienced during test 1, see table 2. The steel deck temperature reached a peak of 138°F by the test's end, figure 59. The center beam supporting the function floor reached a peak temperature of 153°F, figures 60 and 61. The maximum temperature reached by the unprotected portion of the center column in the interstitial space was 165°F, figures 62 and 63. Figures 64 to 67 present plots of temperatures for the protected center column section that was exposed to the fire compartment. The maximum test temperature for the column was 937°F, and it occurred 18 minutes after the furnace burner was turned off. The fireproofed purlins supporting the walk-on deck performed well, figures 68 to 71. As stated in section 5.2.2, all fireproofing stayed on the purlins. This resulted in a maximum purlin temperature for this short test of only 354°F, figure 71. The walk-on deck temperatures are shown in figures 72 to 75. These temperature plots show similarity with the data obtained in test 1. The maximum surface temperature measured was 205°F. This again occurred after the burner was turned off, but the overall floor performance is much like that seen in test 1. Temperature plots for the walk-on deck suspension rods and steel tube bracket are shown in figure 76. Heat transfer through the purlins and the suspension system was clearly reduced as a result of the fireproofing remaining in place. The temperature of these structural elements remained significantly low throughout the test exposure. Figures 77 and 78 provide information on duct temperatures and air temperatures in the interstitial space. Again, these temperture plots show similar performance to that experienced with the first test. However, a major difference is seen in figure 79 when compared with figure 49 of test 1. Test 2 shows very little movement in purlin deflection measurements. Since the purlins and walk-on deck system of test 2 appeared to maintain much of their initial strength after this aborted test, it was decided to conduct another full two hour test on the same assembly in an attempt to obtain additional information. Only the fire protection on the column and pier was replaced.

5.3 Test 2A Fire Endurance for Lightweight Concrete Walk-on Deck System

The record showing the average furnace temperature throughout the two hour test is presented in figure 80. It should be noted that the assembly exposed to this standard fire test was the same assembly tested for 1.5 hours the day before. This should be kept in mind when comparing test results. The gypsum board protection on the column and pier was replaced for test 2A.

5.3.1 Test Observations, Test 2A

Time, hr:min:sec	Test begins at 1:48 p.m., 11/8/83
00:00:00	Ignition
00:00:30	Burner ignition resulted in significant turbulence in the furnace compartment. All fireproofing remained in place on the purlins.
00:01:20	The gypsum board paper has ignited and is burning off around the column.
00:05:10	All of the fireproofing on the purlins is still in place, and all of the paper on the gypsum board protecting the column has burned off.
00:09:30	All fireproofing on the purlins is still in place.

00:15:00	Steam is developing in the interstitial space, but visibility is good.
00:21:30	The metal deck is beginning to glow red as a result of heating.
00:26:30	Steam is still developing in the interstitial space, but visibility is still good. The opposite wall across the compartment is visible.
00:35:00	All fireproofing is still in place on the purlins.
00:50:00	The gypsum board is totally in place around the column, and all fireproofing is in place on the purlins.
01:13:15	Steam is noted coming from the walls enclosing the interstitial space.
01:17:00	The fireproofing is still in place on all of the purlins, and the gypsum board joints have opened on the column to about 1 inch.
01:19:00	Steam has completely obstructed view in the interstitial space.
01:21:00	The first layer of gypsum board has dropped off of the column on the burner side.

01:30:00	All fireproofing is still in place on the purlins, and the entire first layer of gypsum board has dropped off of the column. The second layer of gypsum board is still totally in place.
01:45:00	A piece of fireproofing about 1.5 to 2 feet long has dropped off of purlin "C".
01:51:00	A significant volume of steam is coming from the gypsum board walls enclosing the interstitial space.
01:53:00	All of the fireproofing is still in place on the purlins except the 2 foot long section that dropped off earlier.
02:00:00	Gas supplying the burner was shut off.

5.3.2 Post Test Observations, Test 2A

1. Most of the fireproofing is still in place on the purlins. A section about four feet long has dropped off of purlin "A" in quadrant I. Only half of the two inch thickness has dropped off. The wire mesh on the purlin is not visible, figure 81.

2. The floor is sagging between the purlins about 2 inches.

3. The center purlin has lost a five foot long section of fireproofing about one inch thick on the side between quadrants I and IV.

4. The bottom layer of gypsum board is still in place around the column. The gypsum board pulled away from the metal studs where screws were not attached.

5. The metal deck joint opened at the location where the return duct penetrates the walk-on deck. The metal is sagging about 6 to 7 inches. The metal deck pulled away from the concrete.

6. All fireproofing remaining on the purlins exhibits cracking.

5.3.3 Discussion of Test Results, Test 2A

Heat transmission through the functional floor during the second exposure of the test assembly was limited, figures 82 to 86. The maximum temperature on the unexposed surface of the functional floor was 88°F. The steel deck supporting the floor experienced a maximum temperature of 156°F which was 18°F more than that during test 2, figure 87. In addition, the center beam supporting the walk-on deck also showed higher temperatures than recorded in tests 1 or 2, figures 88 and 89. The maximum temperature in this test for the beams was 201°F. The center column in the interstitial space also performed well during this second exposure, figures 90 and 91. It should be remembered that the gypsum board system protecting the center column in the fire compartment was completely rebuilt for test 2A. As seen in figures 92 to 95, the column did not remain adequately protected in the fire compartment. A single point temperature failure occurred at 1 hr. 35 min. into the test. This occurred at the six foot high point. The temperature limits were exceeded at four other locations some 15 to 20 minutes later. The single point failure temperature for the column is 1200°F. Even though this failure occurred in the fire compartment, the heat transfer through the column did not result in failure condition in the interstitial space. The fireproofing protecting the purlins remained in place on all purlins during most of the second exposure, figures 96 to 99. This fireproofing gave protection for a cumulative exposure time of 3.5 hours between the two different fire test exposures. The maximum single point temperature on a purlin was 546°F, well below the temperature limit for beams. The woven wire mesh on purlins "A" and "B" helped to hold some of the fireproofing on the purlins resulting in clearly improved performance as compared to test 1.

The walk-on deck during this test generally performed better than the walk-on deck in test 1, figures 100 to 103. This deck did not show the amount of cracking noted at the end of test 1. The suspension rod and steel tube bracket temperatures are presented in figure 104. Temperatures recorded for the dummy air conditioning ducts, figure 105, are similar to results obtained during tests 1 and 2. Air temperature in the interstitial space reached a maximum of 331°F. This is only 36 degrees higher than that experienced in test 1. Particular attention was paid to the purlin deflections recorded during this test, figure 107. In test 1, the deflections were random, and in test 2 the purlins moved very little. During this test the purlins showed a gradual movement in the downward direction. This movement was attributed in part to the gradual degradation of the fireproofing combined with the

90 lbs/lin ft load on the purlins. This type of movement was more representative of that expected in a test of this type.

6. DESCRIPTION OF GYPSUM WALK-ON DECK SYSTEM

After the three tests conducted on the two lightweight concrete walk-on deck systems were completed, the tested walk-on decks were removed from the structure. New suspension rods and W6x9 purlins were fabricated and hung in test bay #1. These new steel elements, identical to those tested earlier, formed the structural base for the poured gypsum deck system, figure 108. The modifications made in tests 2 and 2A that included extra nuts and washers used on purlin/bracket connections were also used on the gypsum deck assembly. Truss tee subpurlins, used as components of this system, were positioned between the main purlins with a center to center spacing of 30 inches. The subpurlin flanges were spot welded to the lower flanges of the W6x9 purlins. The subpurlins, manufactured by Keystone Steel and Wire* (style number was 000-5-14-2), were specified by the Veterans Administration. After the purlins were fastened in place, one inch thick glass fiber formboard was laid on the flanges of the subpurlins. Where joints occurred between the glass fiber formboards, sheet metal tees were positioned between subpurlins to support the butt joints. When all of the formboard was layed, woven wire mesh, as described in section 3, was laid directly on top of the board covering the

*Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

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entire surface. At this point, instrumentation, as described in section 7, was placed into the deck system. Gypsum concrete with a cured strength of 500 lb/ft^2 was mixed and poured over the formboard and wire mesh to a thickness of two inches. The gypsum walk-on deck was protected from the weather and ventilated during curing in an attempt to help dry the system before testing.

The bottom flanges of the W6x9 purlins were coated with fireproofing described in table 2. This was the same type of fireproofing used in tests 2 and 2A. Again, two of the three purlins, A and B, had woven wire mesh wrapped around the bottom flanges before the fireproofing was applied. As before, this was done to improve mechanical bonding of the fireproofing to the purlins. One purlin did not have wire mesh attached so that a comparison could be made. After 40 days, penetrations for the dummy air conditioning ducts were cut in the deck. The ducts and firesafing were installed, as described in section 3.2. These ducts were also plugged on the exterior end and the same type of air diffusers used in tests 1, 2, and 2A were attached to the fire compartment ends.

6.1 Special Instrumentation for Gypsum Walk-On Deck System

Most of the temperature measurements taken in tests 1 through 2A were also made when the gypsum walk-on deck was tested. However, a major difference in temperature measurement points in the gypsum test relates to variations in the gypsum deck design. Four temperature measurements were made through the thickness of the gypsum deck system, figure 109a. One thermocouple measured the temperature at the glass fiber formboard on the fire exposed surface. Another measured the temperature at the gypsum deck/formboard interface. A third was used to obtain the center gypsum core temperature and the fourth was used for unexposed surface temperature. This set of measurements was made at two deck locations, figure 110. A second major difference appears with temperature measurements made on the subpurlins, figure 109b. Subpurlin temperature measurement locations on the walk-on deck are shown in figure 110.

All of the thermocouples mentioned above were stainless steel sheathed, type K, thermocouples with an outside jacket diameter of 0.125 inch. The top thermocouple on each of the subpurlins was attached by drilling a shallow 0.187 inch diameter hole, placing the thermocouple into the hole, and peening it into place. The thermocouples on the lower flanges were wire tied to the flange surface.

7. TESTING OF POURED GYPSUM WALK-ON DECK SYSTEM

The gypsum walk-on deck system was tested 55 days after it was poured. The system was tested with the 90 lbs/lin. ft. load applied to each of the W6x9 purlins. This test was conducted for a period of 2 hours and 30 minutes. The test was extended beyond the usual two hour time period because the walk-on deck's relative humidity at middepth was 98 percent and because there was a desire to push the walk-on deck to a point where it no longer presented protection for the interstitial space. Test results for this fire exposure are presented in section 8.

8. TEST RESULTS FOR POURED GYPSUM WALK-ON DECK SYSTEM

8.1 Test 3 Fire Endurance for Gypsum Walk-on Deck System

A record of the average furnace temperature for test 3 as compared to the standard time-temperature curve is shown in figure 111.

8.1.2 Test Observations, Test 3

Time, hr:min:sec	Test begins at 9:45 a.m., 11/22/83
00:00:00	Ignition
00:01:08	Glass fiber turned dark. Gypsum board paper burned off on the column.
00:03:45	Smoke and steam noted in the interstitial space.
00:05:29	About 1 inch thickness of fireproofing dropped off of N.E. end of purlin "C", in quadrant IV. Drop out is about 5 feet long.
00:09:37	Glass fiber board is starting to turn white and is shrinking. Metal corner bead on the column is warping.

00:11:42	Smoke and steam is still increasing in the interstitial space, but the opposite wall is still visible.
00:17:48	Small pieces of glass fiber are dropping from the bottom of the walk-on deck.
00:22:57	The gypsum deck is starting to show in patches where the glass fiber has dropped off.
00:26:10	Visibility in the interstitial space is almost zero.
00:28:12	A large piece of fireproofing on purlin "C" in quadrant III dropped off. Large gaps were noted between the fireproofing and gypsum deck where the glass fiber board has burned out. The fireproofing at these locations is unsupported which is causing the dropouts.
00:33:39	Fireproofing is dropping off of purlin "A", in quadrant II.
00:39:28	Steam is coming from around the interstitial space.
00:43:54	Truss tee is sagging about 0.5 to 1.0 inch on the east side of the center column.
00:54:11	All of the glass fiber board has dropped off of the deck at this point and the gypsum deck is fully exposed to the furnace temperature.

01:00:00	All of the gypsum deck is in place with a sag of about 0.5 to 1.0 inch noted between the purlins.
01:12:16	Gypsum deck around duct opening is starting to crack and chip off. The subpurlin next to the duct opening in quadrant IV is sagging about 1 to 2 inches.
01:18:34	The primary purlins in the walk-on deck system appear to be straight with no sag.
01:21:18	The first layer of gypsum board on the column is starting to crack.
01:24:50	Long cracks are noted in the gypsum deck between the subpurlins.
01:36:50	Subpurlins are sagging between 2 and 3 inches, and the primary purlins are basically straight.
01:39:00	First layer of gypsum board on the column is opening up to about 1 inch at the corners.
01:47:01	Gypsum deck between subpurlins is sagging about 2 to 3 inches in places. Many long cracks between the subpurlins are noted.

01:53:46 A piece of fireproofing dropped off of purlin A in quadrant II.

01:56:00 Gypsum deck between the subpurlins is sagging from 3.0 to 3.5 inches with large long cracks.

02:18:30 One inch wide random cracks are showing in the gypsum deck.

02:25:59 Last layer of gypsum board on the column, burner side, dropped off leaving the column exposed. Gypsum deck is sagging 3.0 to 5.0 inches in quadrants III and IV.

02:31:00 Test is terminated.

8.1.3 Post Test Observations, Test 3

The walk-on deck in quadrant III has sagged about one foot. A hole approximately 4 inches in diameter has penetrated the deck at that point.

A one inch wide crack is open through the walk-on deck between the two center subpurlins at quadrants III and IV. The crack penetrates the deck into the interstitial space.

Both ducts have settled about six to eight inches at the penetration, and openings are observed through the walk-on deck at the penetrations, figure 112.

The wire mesh in the gypsum walk-on deck is visible across the entire fire exposed surface in the furnace compartment, figure 112.

All subpurlins visibly appear to be still firmly attached to the purlins.

All fireproofing on purlin "C" that was not covered with woven wire mesh has fallen off, figure 112. The two purlins with the woven wire mesh attached still have fireproofing intact on their full length.

Purlin "C" is bowed up in the center. As a result, the suspension rod was bent out of plumb about six inches, figure 113.

8.2 Discussion of Test Results, Test 3

In test 3, the functional floor temperatures showed that the walk-on deck provided significant resistance to heat flow. Figures 114 through 118 show that the maximum temperature on the top functional floor surface never exceeded 115°F during the 2.5 hour exposure. The temperature of the steel deck supporting the functional floor had a maximum temperature of 176°F, figure 119. This temperature was less than that measured in test 1, but was more than 35°F higher than the maximum steel deck temperatures measured in tests 2 and 2A. These maximum deck temperatures are still well below any critical temperatures specified by the test procedure. Temperatures for the central beam supporting the functional floor are shown in figures 120 and 121. The highest temperature measured was 304°F which is substantially below the critical temperature for that structural element. This temperature was measured after 2.5 hours of test exposure. The unprotected column in the interstitial space also showed relatively low maximum temperatures, figures 122 and 123. In figure 123, the measurement made at the column flange lip was discarded because of a thermocouple failure. The flange and web temperatures show similar results with measurements well below the critical 1200°F value. The protected part of the center column also performed well in this test, figures 124 to 127. After the initial two hours, the maximum temperature was still more than 60°F below the failure point.

Walk-on deck purlins did not achieve the same degree of success. This is shown in figures 128 to 131. The purlin which crosses quadrants III and IV experienced peak temperatures in excess of 1800°F on the bottom flanges. The earliest single point critical temperature limit was reached in quadrant III at about 36 minutes into the test. The two measurement locations on this purlin also show failures for average temperature. These failures occurred at 1 hour 11 minutes for the purlin location in quadrant III and 1 hour 53 minutes for the purlin location in quadrant IV. Test observations noted in section 8.1.2 show that these critical temperatures relate directly to the fireproofing dropping off the purlin. This purlin, which failed, did not have its bottom flange wrapped with wire mesh before the fireproofing was applied. The other purlins that did have wire mesh wrapping performed well, and it indicates that it is important for purlin protection when glass fiber formboard is used in a system of this design. The observation noted in section 8.1.2 stating that large gaps were observed between fireproofing and the gypsum deck, where the glass fiber board burned out, supports this conclusion. The subpurlins' temperatures are shown in figures 132 and 133. These construction elements also experienced significantly high temperatures. However, it should be remembered that the subpurlin flanges were completely exposed to the fire compartment heat. The temperatures on the upper lip reflect the gypsum deck's thermal influence. Gypsum deck temperatures are shown in figures 134 and 135. These plots show that the maximum walk-on deck top surface temperature was 775°F at the end of the test.

Temperature rise for the suspension rods and steel tube bracket are presented in figure 136. Dummy air conditioning duct temperatures are exhibited in figure 137 and the interstitial space air temperature measurements are given in figure 138.

The walk-on deck purlin deflection measurements are shown in figure 139. As can be seen, purlin "C", which crossed quadrants III and IV, moved vertically. This movement was similar to that observed in test 1 when the fireproofing also fell off. The center of the purlin, as mentioned in section 8.1.2, moved upward about three inches. However, in this test the purlin was loaded to full design capacity, but it still moved upward in the center. The other suspended purlin "A" also showed upward movement but not to the same degree. Most of the fireproofing remained on this purlin throughout the test. The center purlins which were attached to the column remained relatively straight. The downward movement shown at the test's end was not clearly evident when observing the structure. However, the permanent upward set of the suspended purlins was clearly observed, figure 113. The bent suspension rod in the picture's center provides some indication of how much the purlin had deflected upward.

9. HEAT TRANSFER MODELING PREDICTIONS

The FIRES-T3 computer program for modeling temperature distribution for structures in fire environments was developed at the University of California under grants provided by the National Science Foundation and National Bureau of Standards [2]. The computer program was designed to evaluate three-dimensional solids or composites that are subjected to fire environments. Options for two-dimensional and one-dimensional heat flow analysis are also available. In this project, the two-dimensional analysis option was used in an attempt to predict heat flow through the lightweight concrete walk-on deck system. Separate predictions were made for the walk-on deck, protected purlins, and unprotected purlins in the walk-on deck.

With the two-dimensional model, the structural assembly is drawn in the form of a nodal mesh using elements which are made up of 4-node isoparametric quadrilaterals and triangles. The mesh used to analyze the three cases described above are shown in figures 140, 142, and 144. Thermal properties data for each material used in the analysis are assigned to the elements. These inputs describe thermal conductivity and specific heat characteristics as a function of temperature. The materials densities also are included, but this input represents only the initial density.

The input for fire environments can be either a linear or nonlinear model. Both of these models include convective and radiative heat flow mechanisms in the predictions. In this case, the nonlinear fire environment model was used where the fire followed the standard NFPA 251 time-temperature curve.

9.1 Predictions for Lightweight Concrete Walk-On Deck

The first prediction and comparison made was for the lightweight concrete walk-on deck system evaluated in test 1. The slab mesh identifying the nodes and elements used in the prediction is shown in figure 140. Elements 7, 14, 20 and 25 represent the steel deck. The remaining elements are for the lightweight concrete. Figure 141 shows a comparison of FIRES-T3 predictions for the walk-on deck with test results obtained from test 1 in quadrant III. Prediction elements 1 and 21, found in figure 140, are compared with surface temperatures over thick and thin walk-on deck sections. As can be seen, these predictions are fairly close with the maximum temperature difference at tests end being 29°F. This represents a maximum difference of 13 percent between the prediction and the actual test results. Purlin comparisons were also made but did not show the same degree of correlation.

9.2 Predictions for Fireproofed Purlin Supporting Lightweight Concrete Walk-On Deck

In this evaluation, purlin temperature data from test 2, quadrant II are composed with FIRES-T3 predictions for a fireproofed purlin. It should be remembered that test 2 ran for 1 hour 30 minutes. However, the computer model provides a prediction for a full 2 hour exposure. The nodes and elements for the combined slab and purlin section are shown in figure 142. As shown, elements 1 through 3 and elements 5 and 6 represent the fireproofing. Elements 4 and 8 represent the steel deck which is attached to the purlins lower flange.

The FIRES-T3 prediction is compared with test data in figure 143. This comparison shows that the predictions for the lower flange were significantly off track. This may be due in part to the fact that thermal properties for the fireproofing had to be estimated since the manufacturer's data were incomplete for the temperature range being studied. However, predictions for the top purlin flange were very close. In this case it is clear that the lightweight concrete walk-on deck was influencing the heat transfer to the upper flange. Walk-on deck temperatures from test 1, figure 141, help demonstrate this. It appears that the computer model handles heat transfer through the floor and fireproofed purlin well. However, the lower flange prediction was not as accurate. It would appear from the temperature plateaus figure 143 that moisture played a major role. It should be noted that FIRES-T3 does not take into account the beneficial effect of moisture.

9.3 Predictions for Unprotected Purlin Supporting Lightweight Concrete Walk-On Deck

This FIRES-T3 prediction was compared with data taken from test 1. The node and element meshes for this lightweight concrete and purlin section is shown in figure 144. For this analysis, two different mesh arrangements were used and therefore two separate analyses were made. One depicts the section where the steel deck flute is open, figure 144a, and the other shows a section where the flute is in contact with the lower purlin flange, figure 144b. Test data for the comparison shown in figures 145 and 146 had to be adjusted in time to fit the prediction plots. It should be noted that these test data start at 13 minutes into test 1 when the fireproofing fell off purlin "C" in quadrant III.

Figure 145 gives the comparison between predictions and test data for the unprotected purlin lower flange. Predicted lower flange temperatures are consistantly lower than those of the test data. By test's end, the temperature difference is more than 260°F. This represents a discrepancy of almost 14 percent, which is similar to that seen earlier.

The prediction for the top flange of the same unprotected purlin is compared to test data in figure 146. Here again the predicted temperatures are lower than those obtained from test 1. The purlin's test data show temperatures more than 16 percent above predicted values at 2 hours. Some of this difference and that seen in figure 145 may be attributed to the 13 minute time shift noted in the test data. During this time period, the total building system did have an opportunity to heat up, but the purlin did not show any significant increase in temperature until after the fireproofing fell off at 13 minutes.

In general, the FIRES-T3 model did provide reasonable predictions. However, for the assemblies actually evaluated it did not provide the accuracy necessary for predicting fire endurance classifications for the systems tested. This is more likely attributable to the program assumptions made regarding the integrity of the assembly during the fire exposure period. It may also, to a lesser extent, result from the accuracy of thermal properties data used for the materials tested. As stated earlier, some of the materials' thermal properties had to be estimated.

10. CONCLUSIONS

1. The unloaded lightweight concrete walk-on deck system suspended by the 0.625 inch steel rods will provide a 2 hour fire endurance rating based temperature limits specified in NFPA 251 for the unprotected steel in the interstitial space and the functional floor above. This rating is clear when the loaded purlins supporting the walk-on deck are covered with a 2 hour rated fireproofing.

2. The unloaded poured gypsum walk-on deck system suspended by the 0.625 in steel rods will also provide a 2 hour fire endurance rating based on temperature limits of 1100 and 1300°F for the unprotected steel in the interstitial space and the functional floor above. This rating also depends on the use of a 2 hour rated fireproofing protecting the loaded suspended purlins.

3. It is not clear that either the lightweight concrete walk-on deck system or the poured gypsum walk-on deck system will provide the required protection to the unprotected steel in the interstitial space or the functional floor above if fireproofing is not used to protect the suspended purlins.

4. Duct penetrations can be adequately protected for 2 hours using the materials and methods described in this report. It should be stressed, however, that the ducts were not left open to provide for free flow of hot gases from the fire compartment.

5. The gypsum board protection fastened to the center column provided a two

hour fire endurance rating based on temperature limits of 1000 and 1200°F to the W14x61 steel column. However, it should be noted that the column was not loaded and the furnace temperature was not evenly distributed along the column's length as would be the case in a column test furnace.

6. The FIRES-T3 computer model will provide an estimate of the temperature rise in construction systems when exposed to the NFPA 251 fire exposure, but the model does not account for changes in the integrity of the system and the presence of moisture..

7. FIRES-T3 computer predictions and other fire prediction methods require accurate materials properties data to produce usable results. There is a need to develop materials property data to assist in the use of computer models.

11. ACKNOWLEDGEMENTS

Mr. Doyle Carrington and Mr. Sid Israel of the Veterans Administration are recognized for their assistance in coordinating the research project and providing technical advice. Appreciation is extended to Mr. William Bailey and his crew of superb technicians: Messrs. Oscar Owens, Charles Veirtz, Mel Womble, Roy McLane, and Gary Proulx. These gentlemen were responsible for constructing, instrumenting, and testing the building systems. Mr. Sam Steel provided technical advice on instrumentation and coordinated data taking activities. Special thanks is given to Mr. David Jeanes for his advice on use of the FIRES-T3 computer model. Keystone Steel and Wire provided the truss tee subpurlins and woven wire mesh for the gypsum deck test. W.R. Grace and

Company, Construction Products Division, provided fireproofing for the purlins and fire compartment for tests 2, 2A, and 3. The Veterans Administration Office of Construction provided funds for this research project.

12. REFERENCES

[1] Standard Methods of Fire Tests of Building Construction and Materials, NFPA 251, National Fire Protection Association, Quincy, MA (1983).

[2] Iding, R., Bresler, B., Nizamaddin, Z., FIRES-T3 A Computer Program For the Fire Response of Structures Thermal, report number UCB FRG 77-15, Fire Research Group University of California, Berkeley, October 1977.

[3] Jeanes, D.C., Predicting Fire Endurance of Steel Structures, paper presented to American Society of Civil Engineers, April 1982.

[4] Federal Specification HH-I-558B, Insulation, Blocks, Boards, Blankets, Felts, Sleeving (Pipe and Fire Covering), and Pipe Fitting Covering, Thermal (Mineral Fiber, Industrial Type) November 1971.

[5] Standard Methods of Fire Tests of Building Construction and Materials, ASTM E119-83, American Society for Testing and Materials, Philadelphia, PA (1983).

Table 1. Fireproofing

Test Number	Manufacturer	Brand Name	Composition	Application Method	Application Rating ASTM E119
1	United States Mineral Products Company	Cafco Blaze-Shield	mineral fibers and cementitious binders	sprayed one-coat	2 hours
2 & 3	W.R. Grace & Company	Monokote 5	cementitious plaster	sprayed two-coats	2 hours

Note: 1. Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

2. Neither the contents of this report nor the fact that the tests were made at the National Bureau of Standards shall be used for advertising or promotional purposes.

Table 2. Weather Conditions

Test Number	Ambient Air Temperature °F	Unexposed Surface Wind Speed at Start of Test ft/s
1	64	2.8
2	58	3.3
2A	66	3.4
3	62	2.9

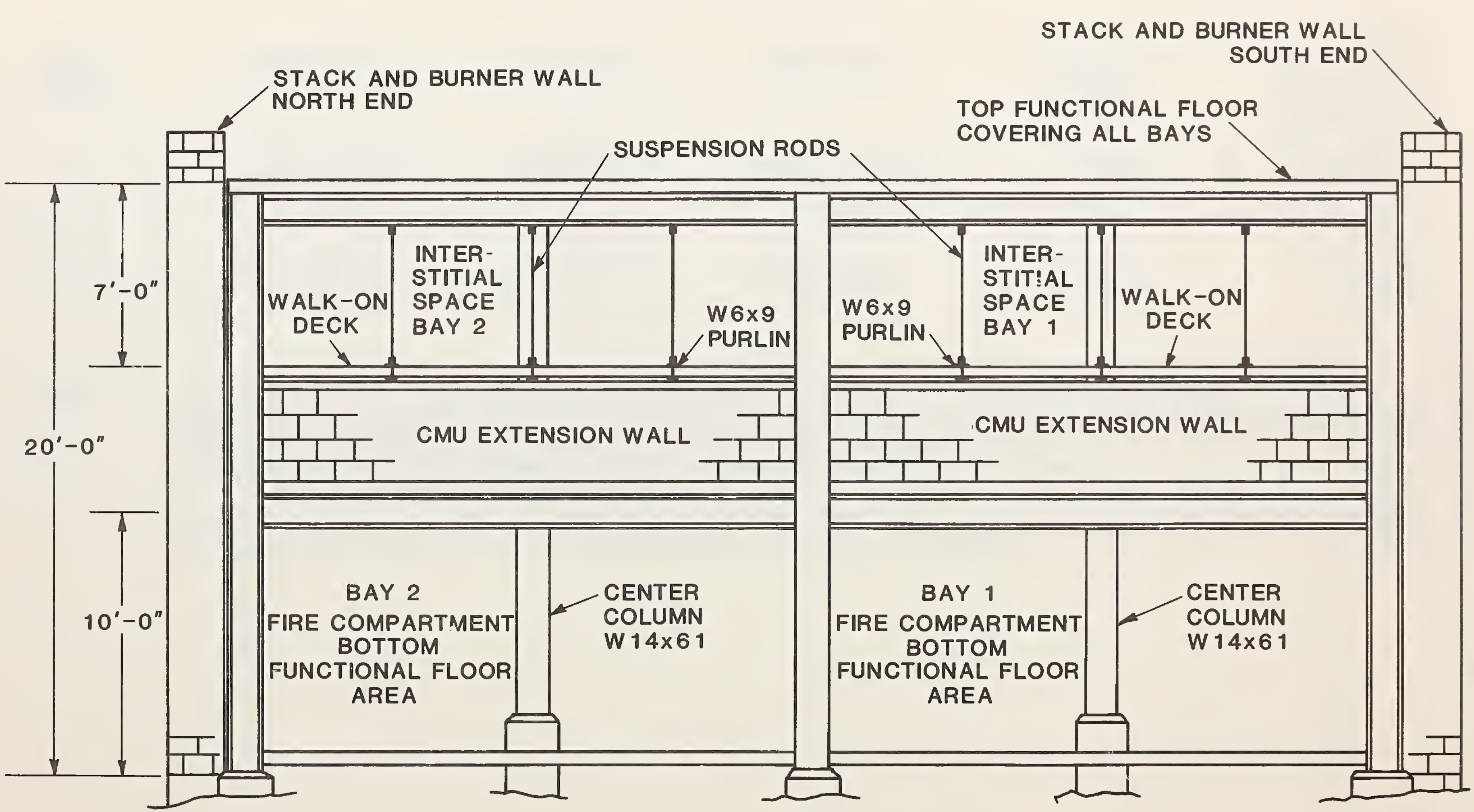


Figure 1. Elevation of fire test structure

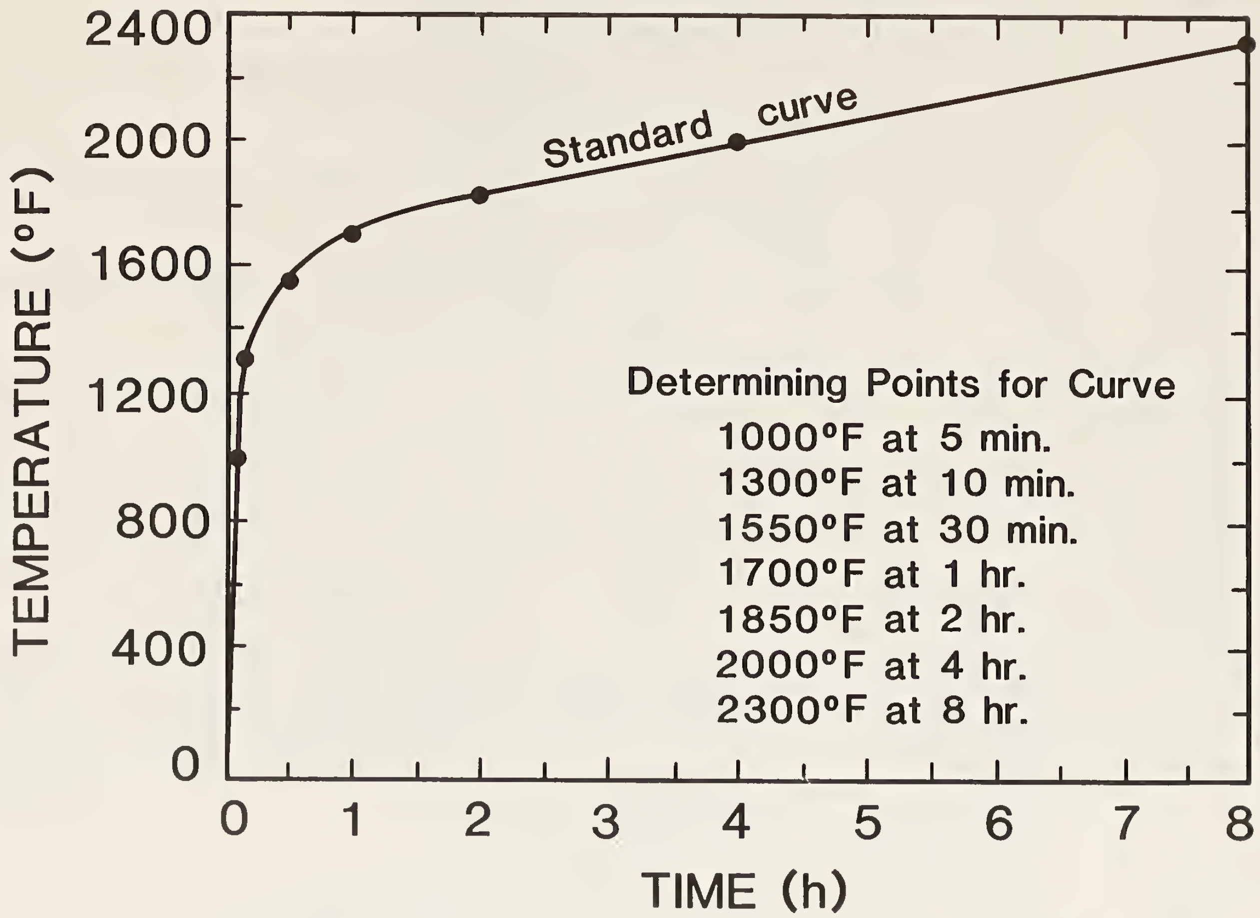


Figure 2. Standard time-temperature fire endurance curve

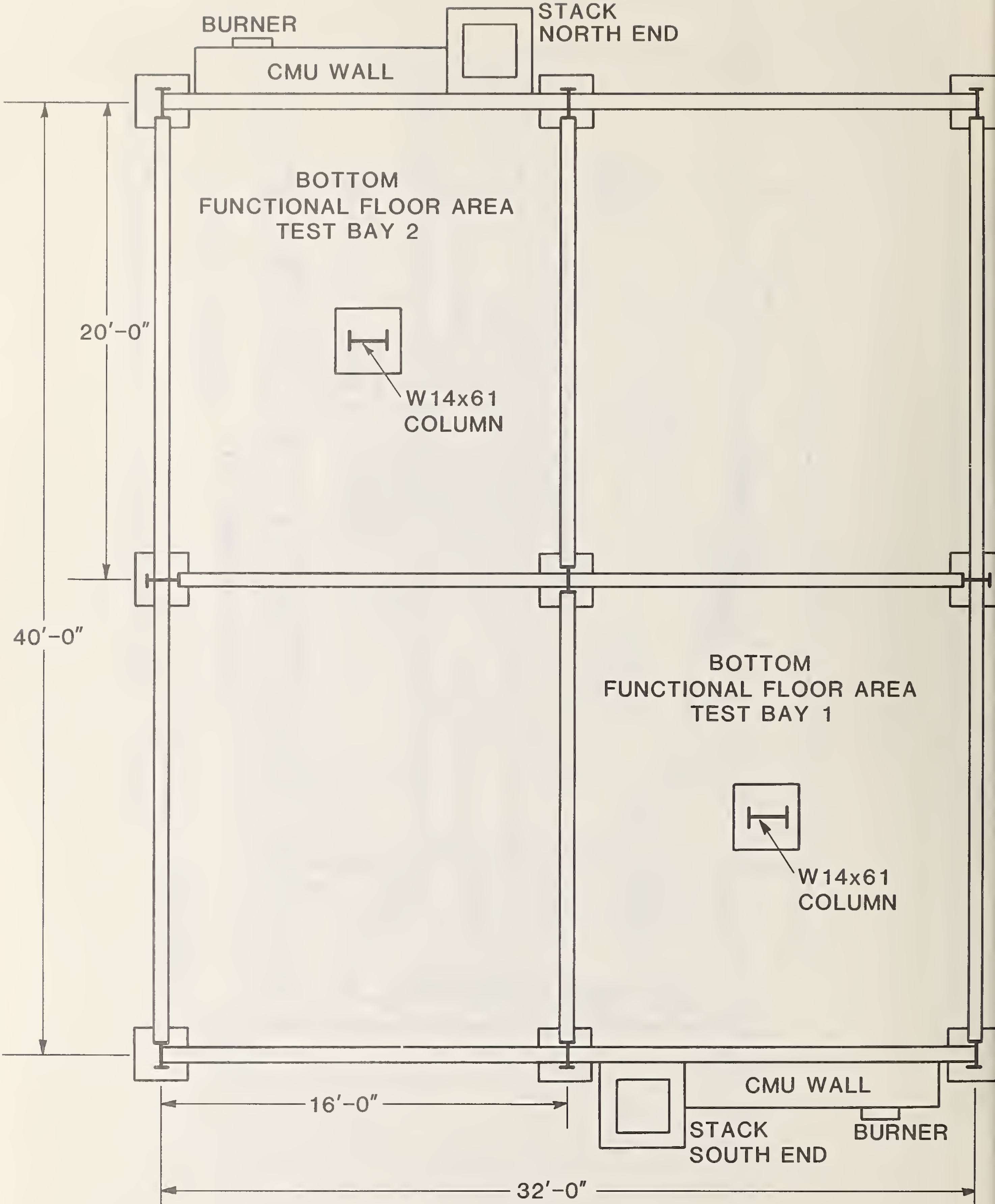


Figure 3. Plan ground level of test structure

Figure 4. Photograph of fire compartment

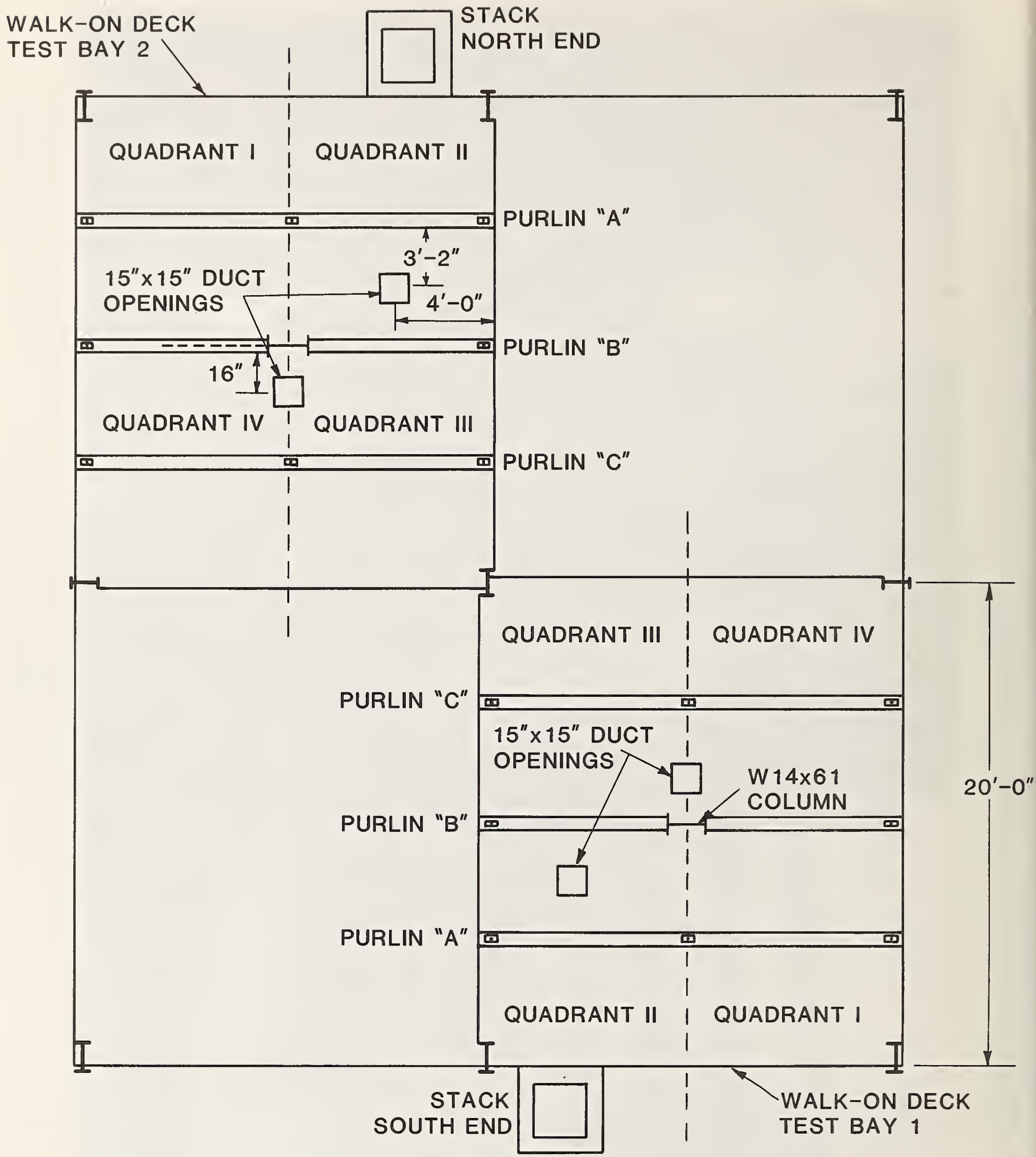


Figure 5. Plan walk-on deck level of test structure

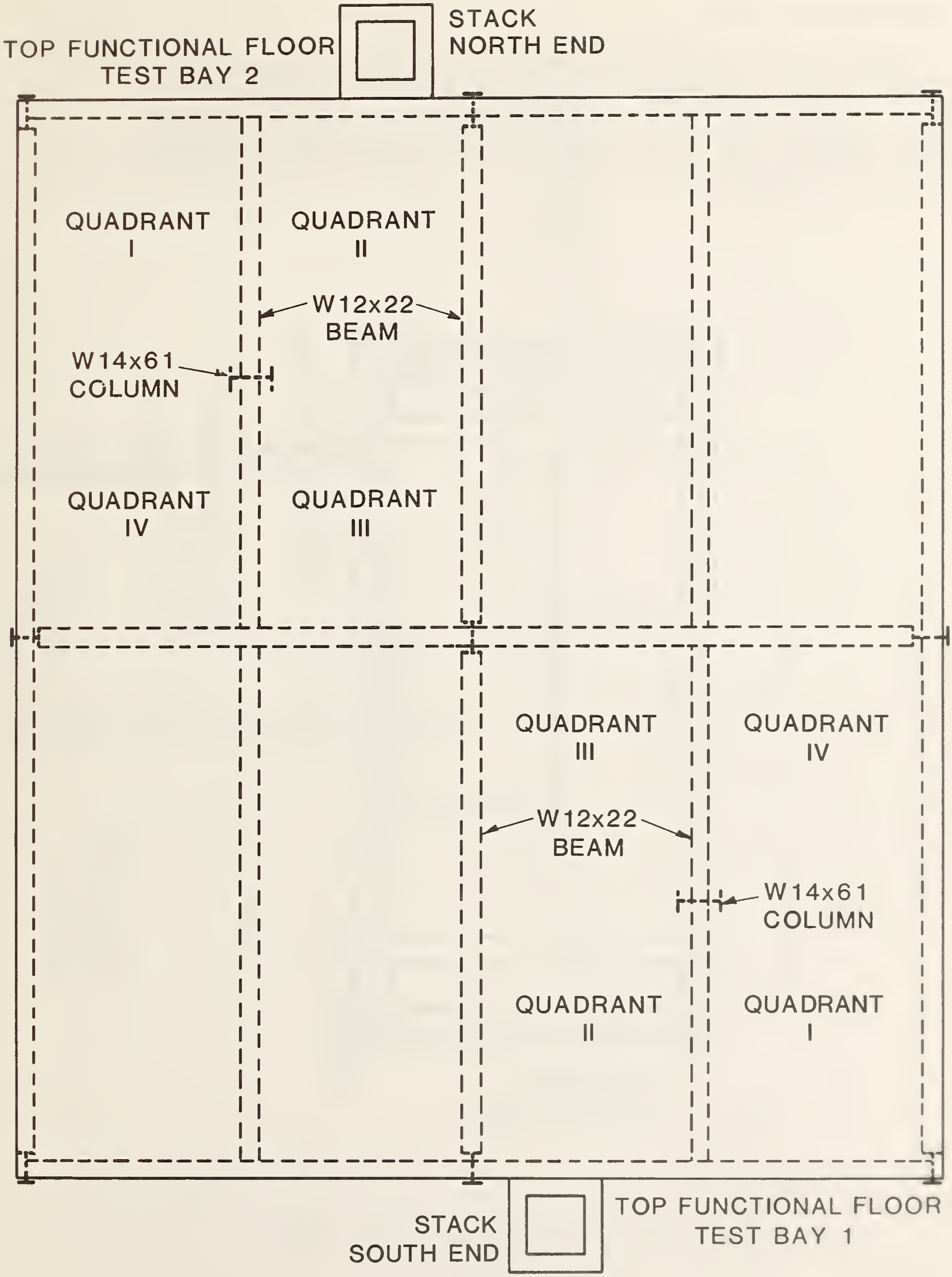


Figure 6. Plan functional floor of test structure

COLUMN FIRE PROTECTION

TWO LAYERS OF 0.625 INCH TYPE-X GYPSUM WALLBOARD SCREW ATTACHED TO 1.625 INCH METAL STUDS LOCATED AT EACH CORNER OF W 14x61 COLUMN WITH 1 INCH TYPE "S" SCREWS 24 INCHES O.C. FOR BASE LAYER AND 1.625 INCH TYPE "S" DRYWALL SCREWS 12 INCHES O.C. FOR FACE LAYER, 1.25 INCH METAL BEADS AT CORNERS ATTACHED WITH 6D COATED NAILS 1.75 INCH LONG, 0.915" SHANK, 0.25 INCH HEADS 12 INCHES O.C.

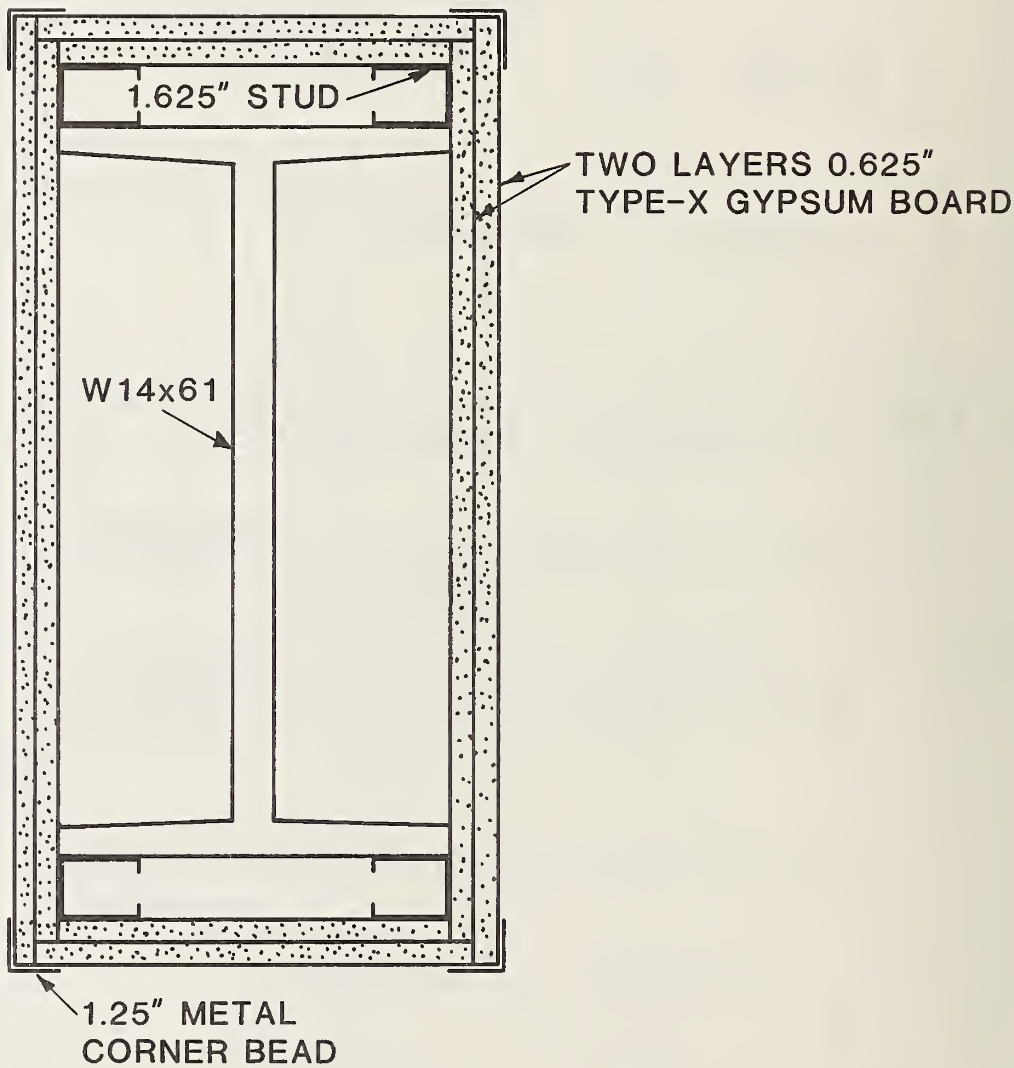


Figure 7. Fire protection for W 14x61 columns

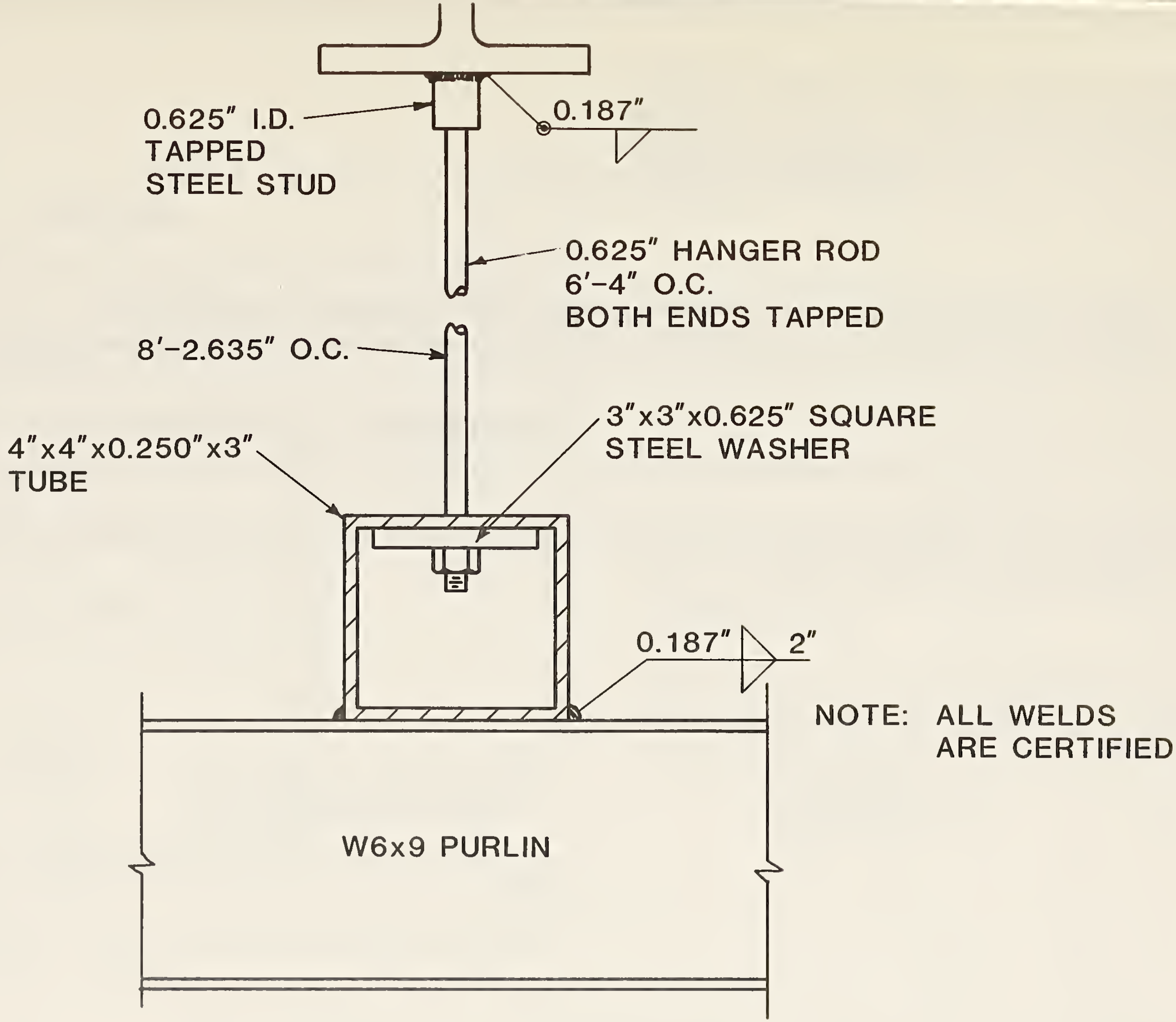
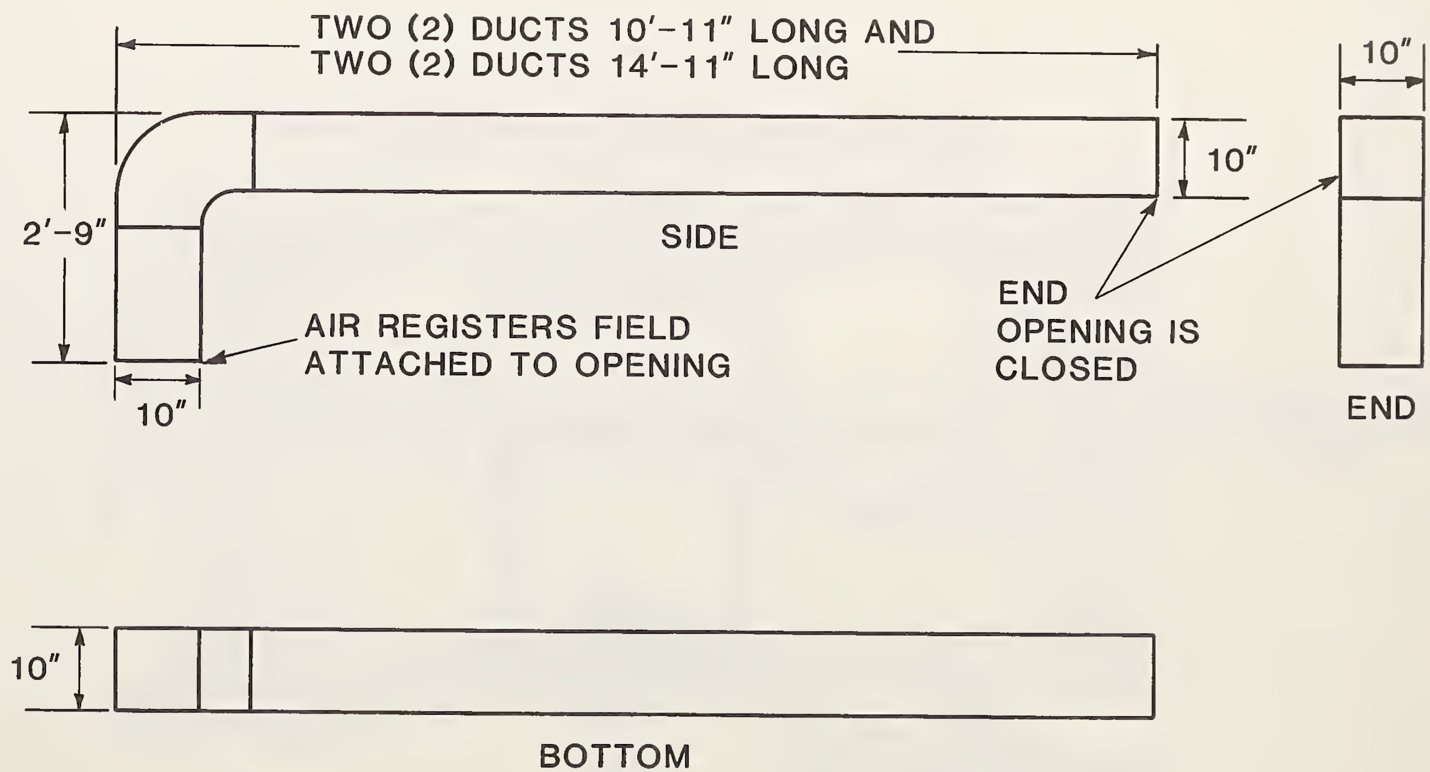


Figure 8. Sketch of welded connections for steel tube to W 6x9 steel purlins



NOTE: All ducts constructed of No. 22 U.S. gage (.030") galvanized sheet steel. All joints and seams air tight. Flush mounted air registers will be fitted to ducts

Figure 9. Details of air conditioning duct construction

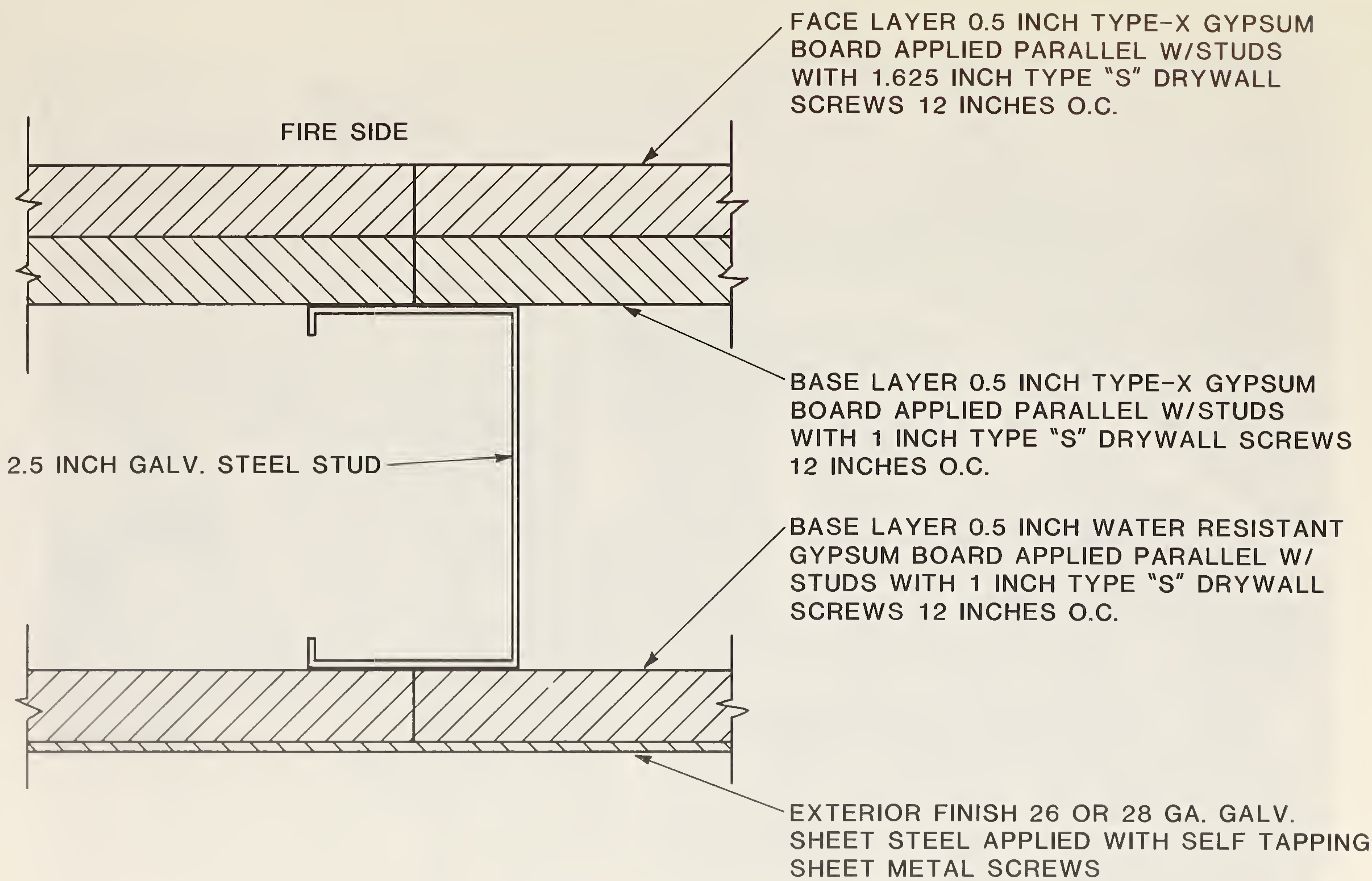


Figure 10. Sketch of wall construction enclosing the interstitial space

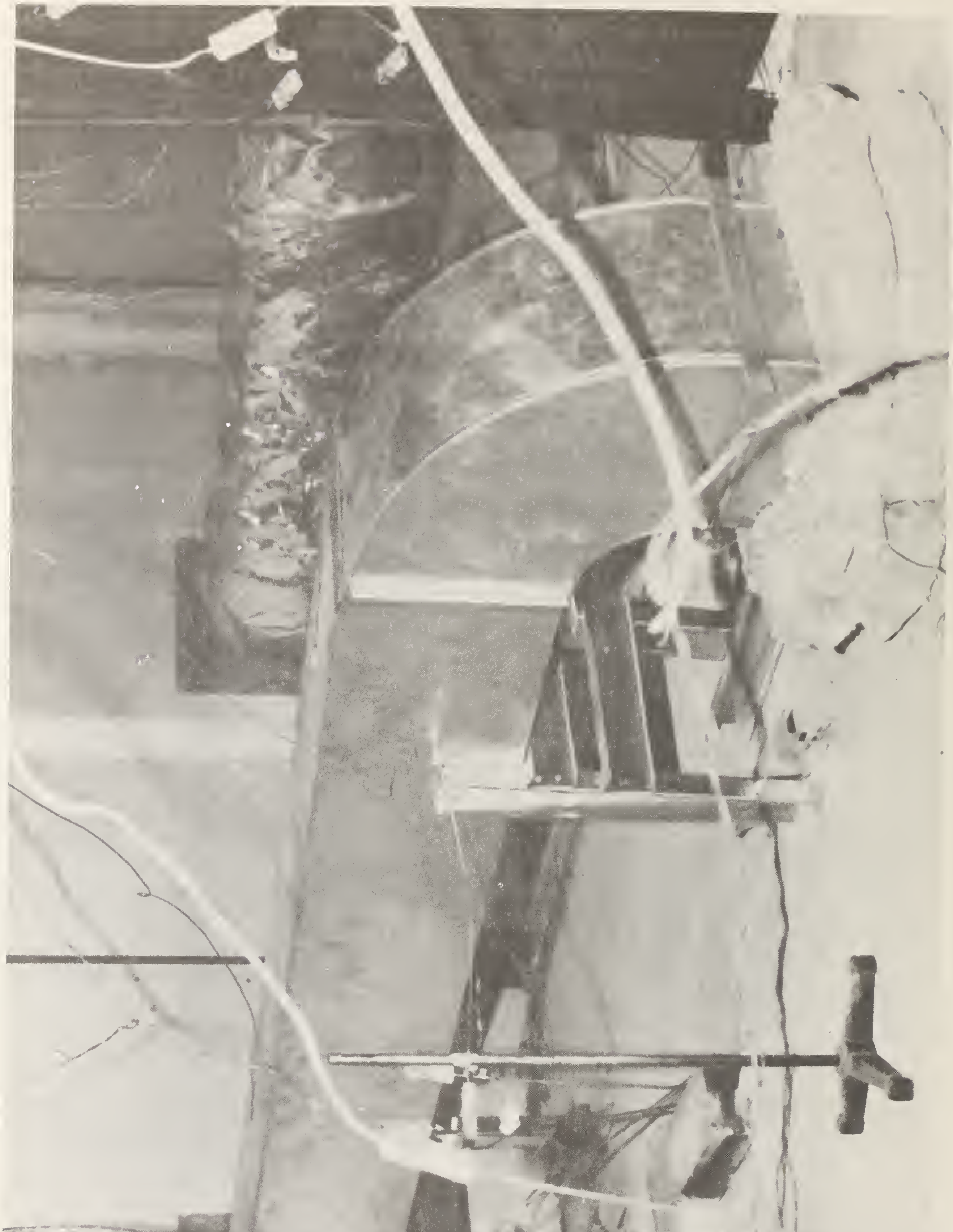


Figure 11. Photograph showing interstitial space

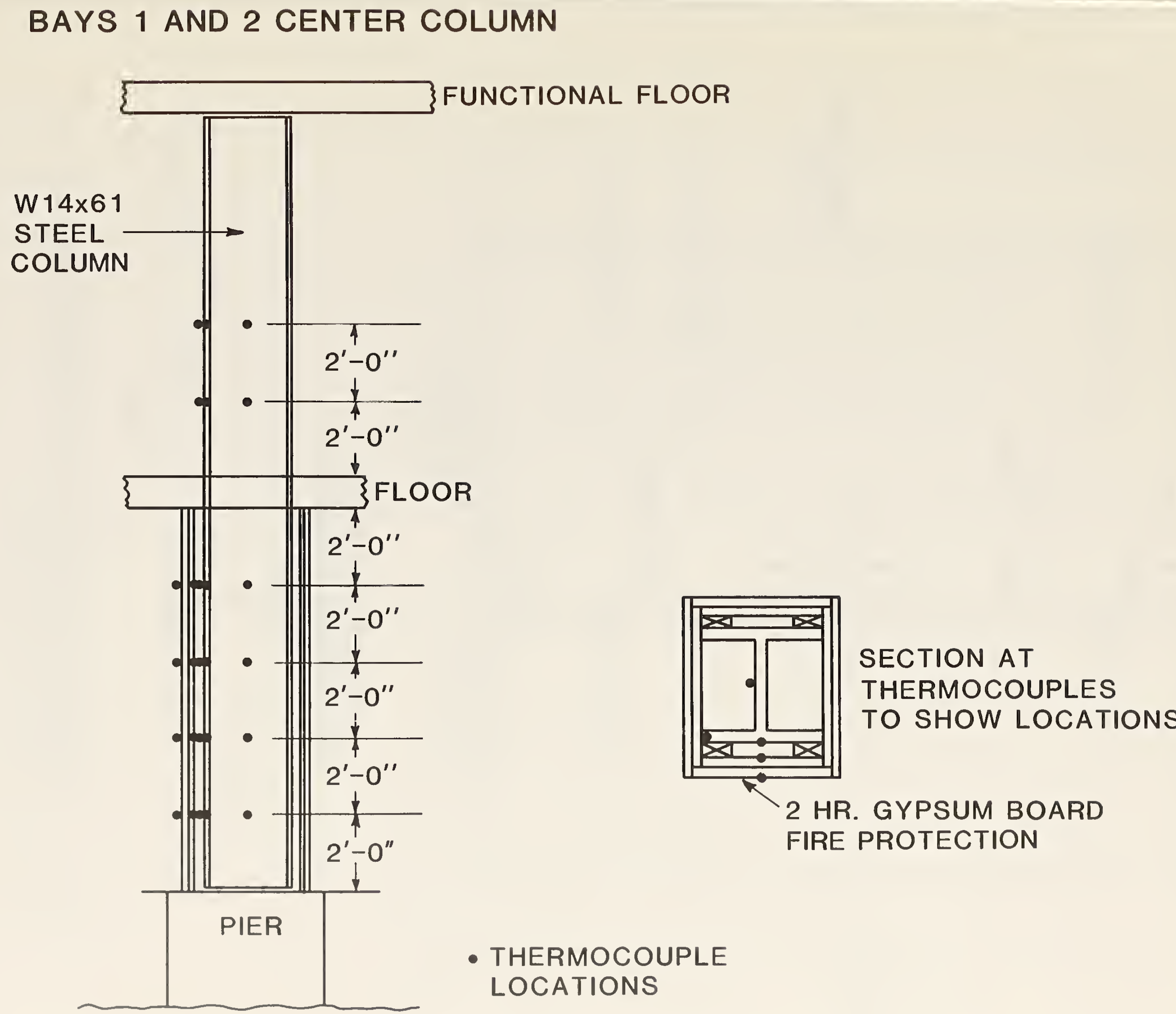
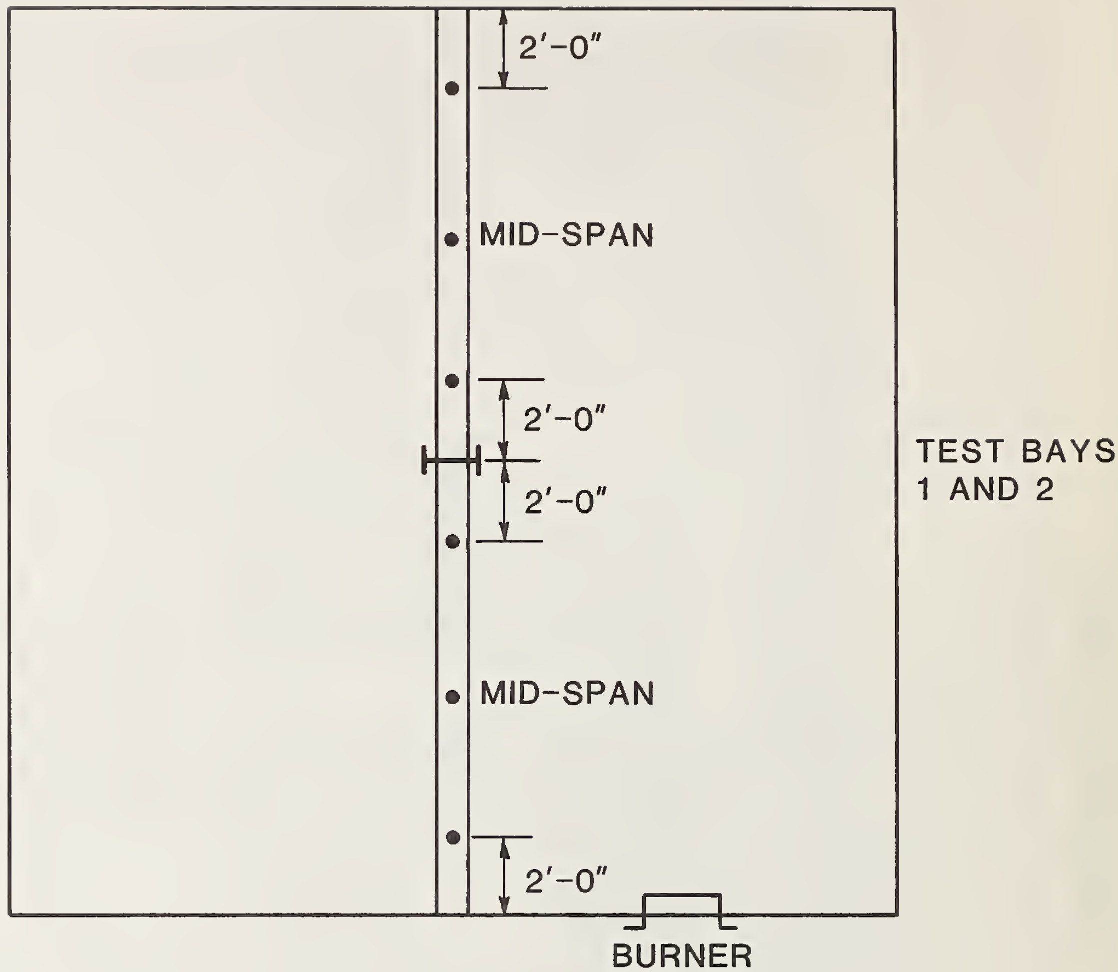


Figure 12. Placement of thermocouples attached to the W 14x61 steel column



SECTION SHOWING
LOCATIONS ON BEAM

Figure 13. Placement of thermocouples on center beams supporting the functional floors

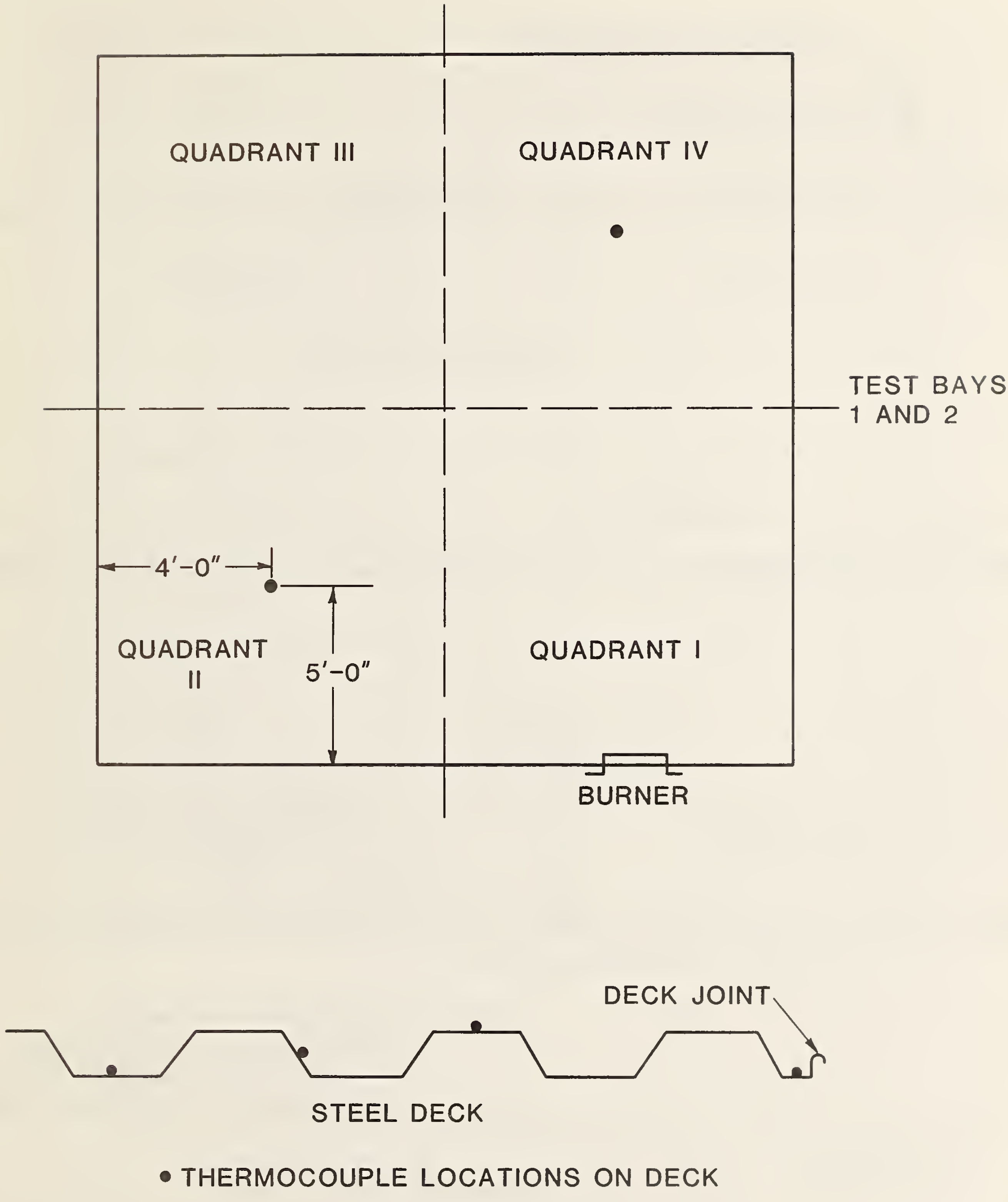


Figure 14. Placement of thermocouples on functional floor steel decks

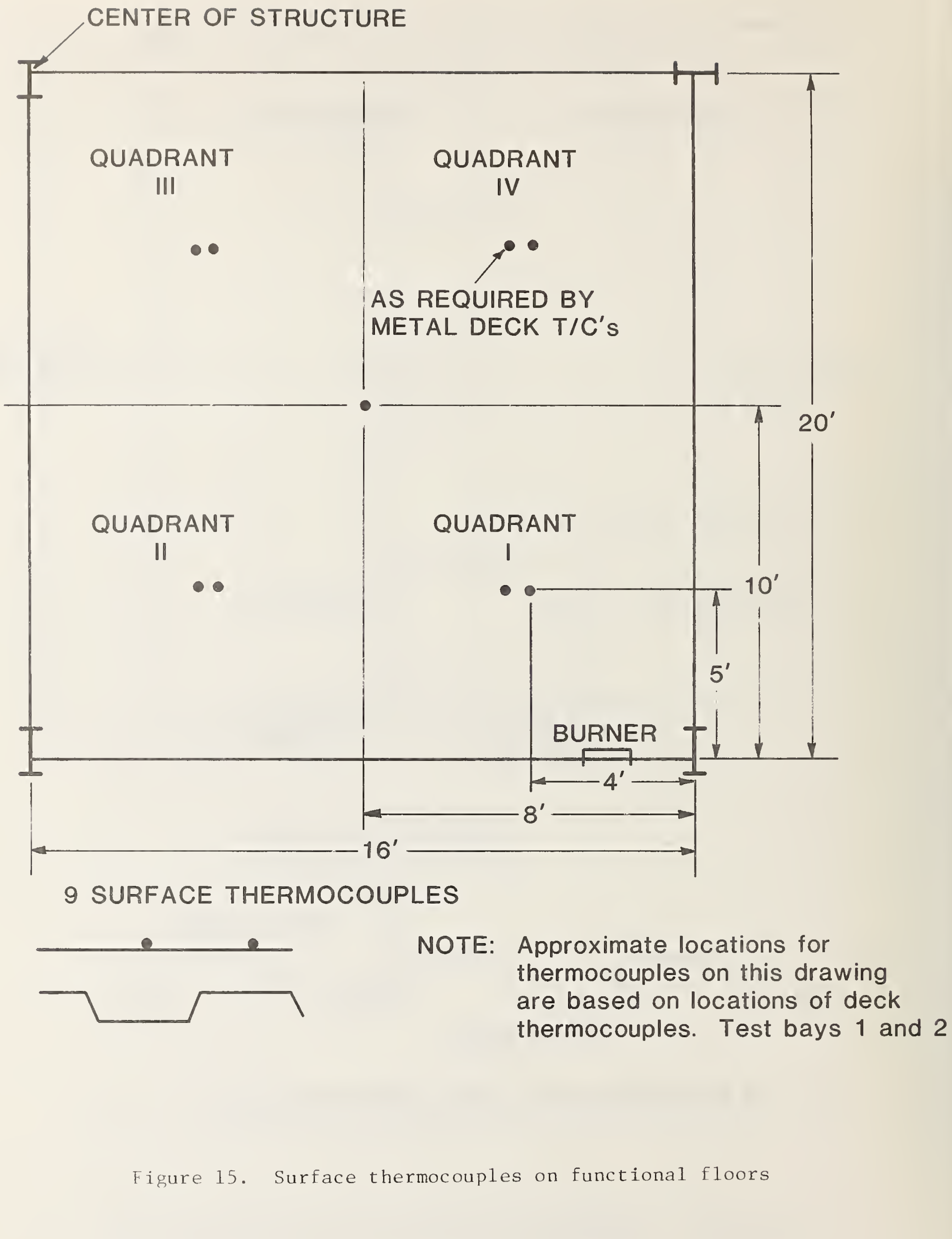


Figure 15. Surface thermocouples on functional floors

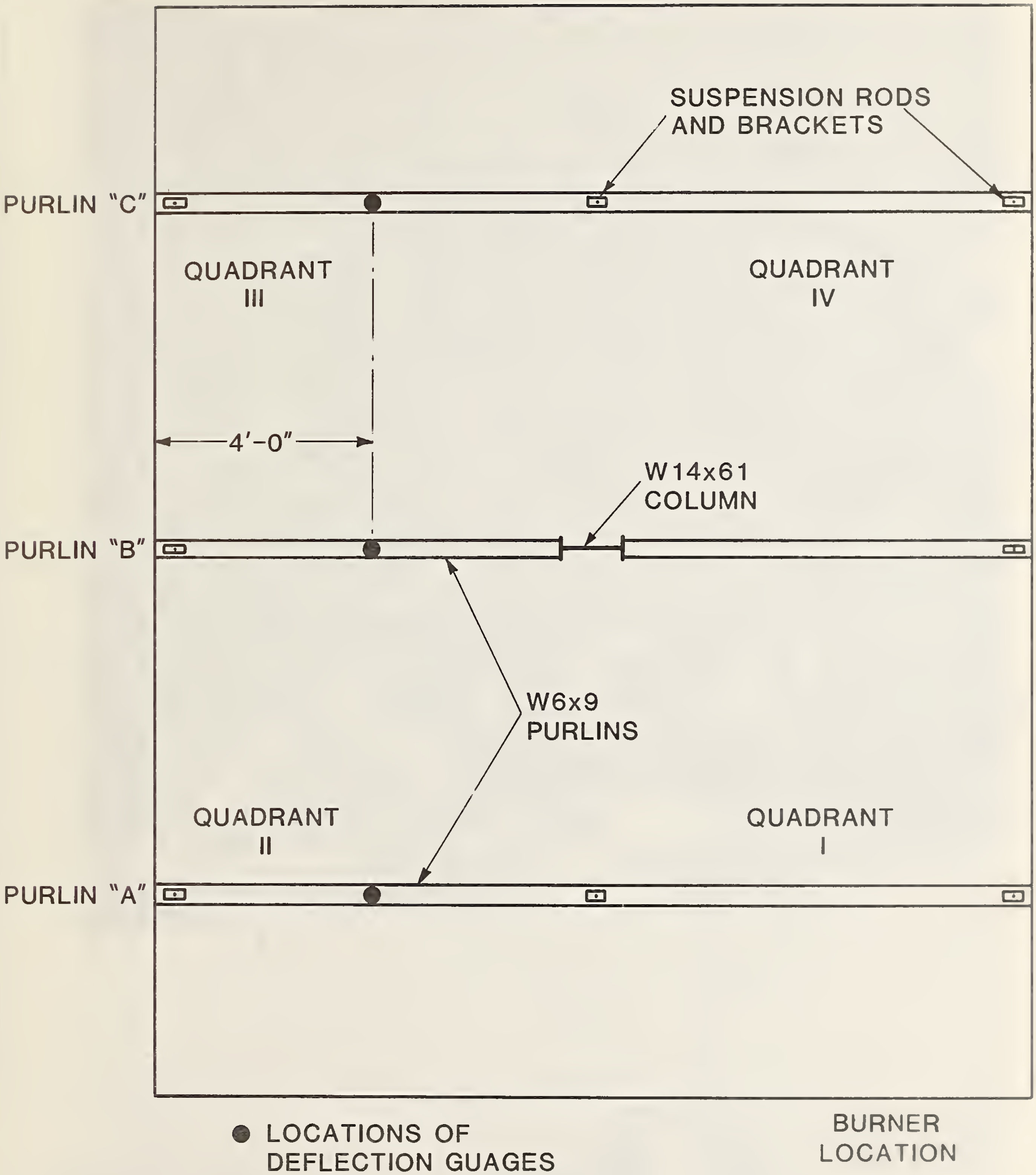


Figure 16. Locations for deflection gauges on purlins

Figure 17. Photograph showing deflection gauge weight on load container

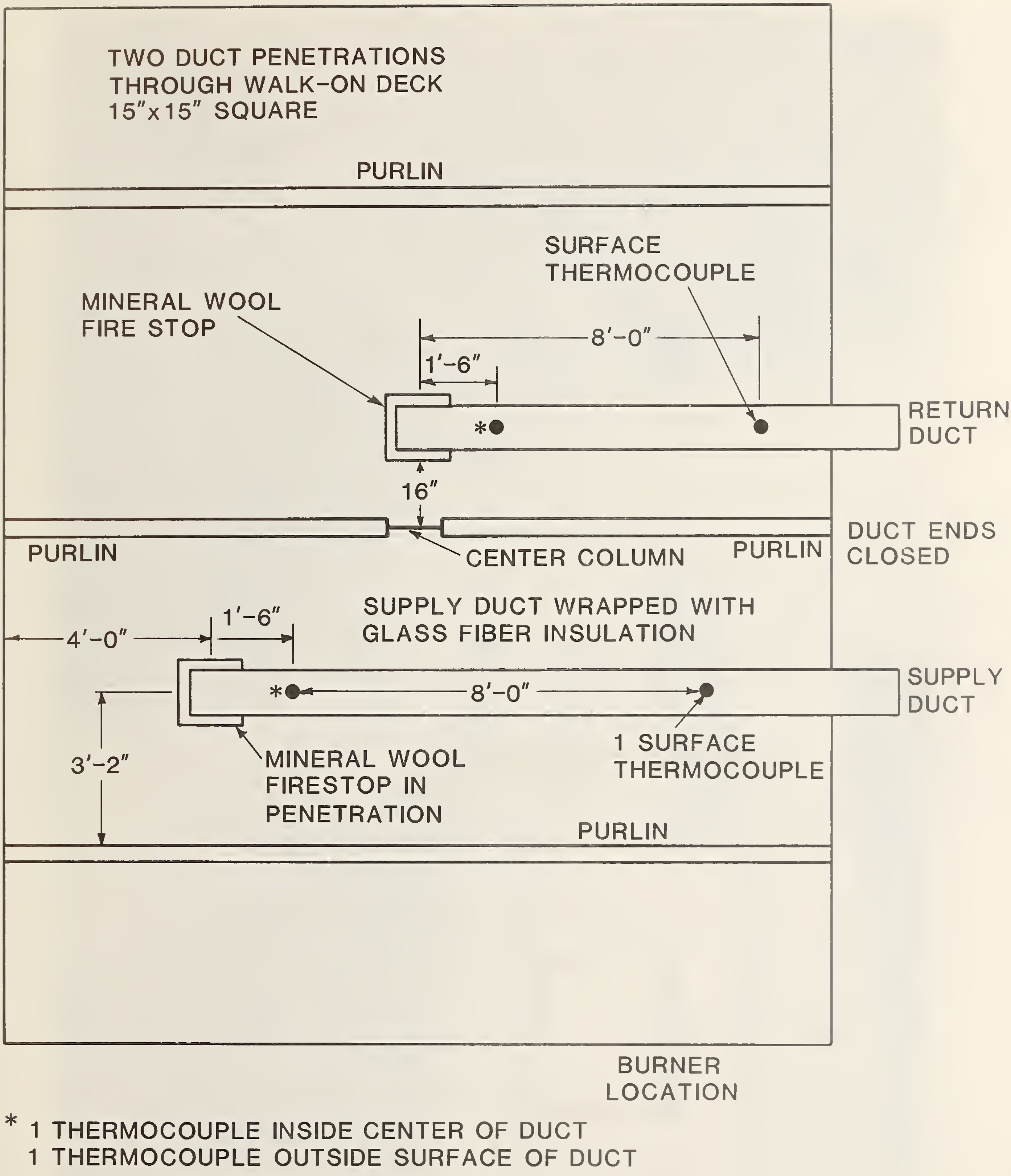


Figure 18. Locations for thermocouples on air conditioning ducts

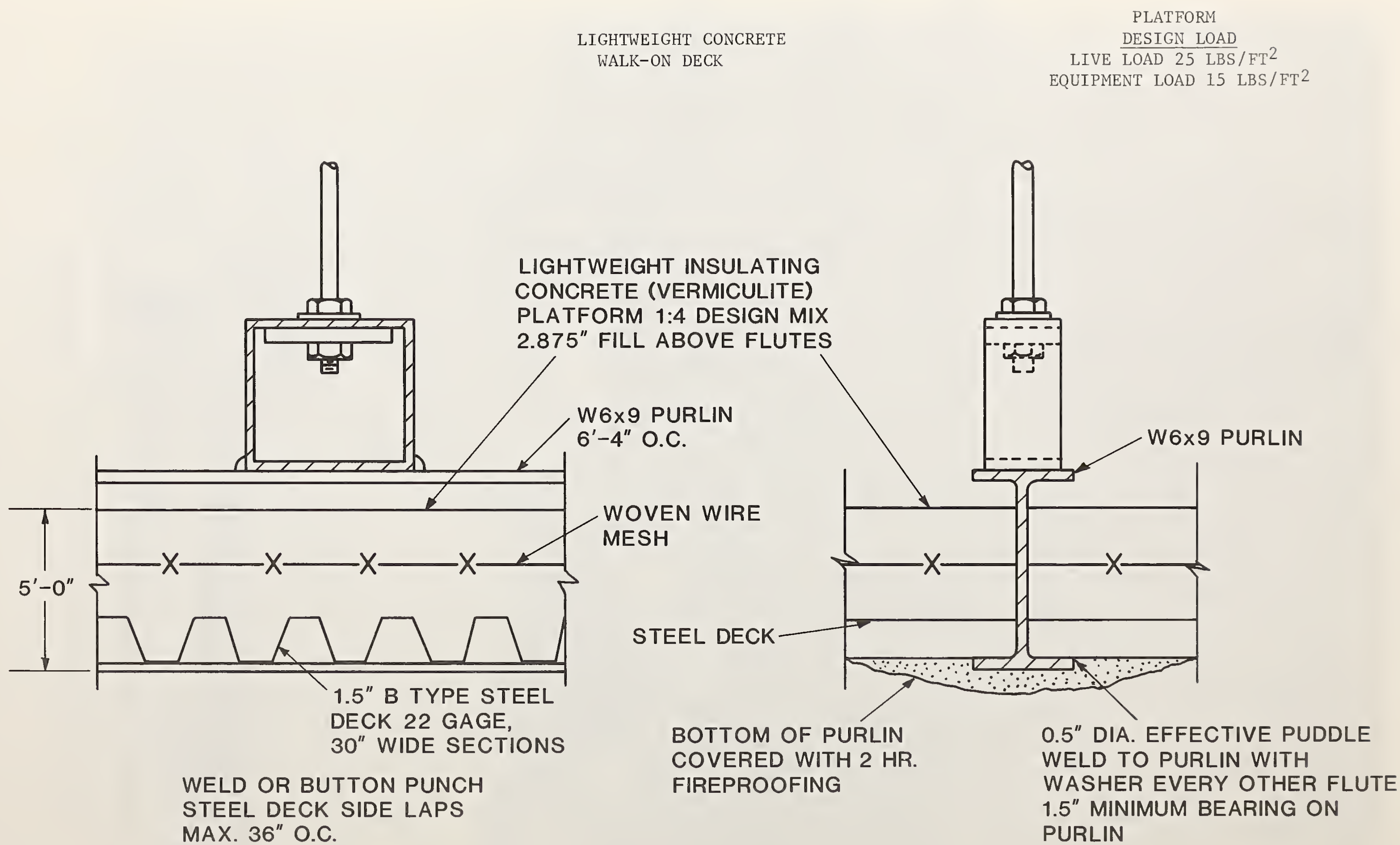


Figure 19. Construction details for lightweight concrete walk-on deck system

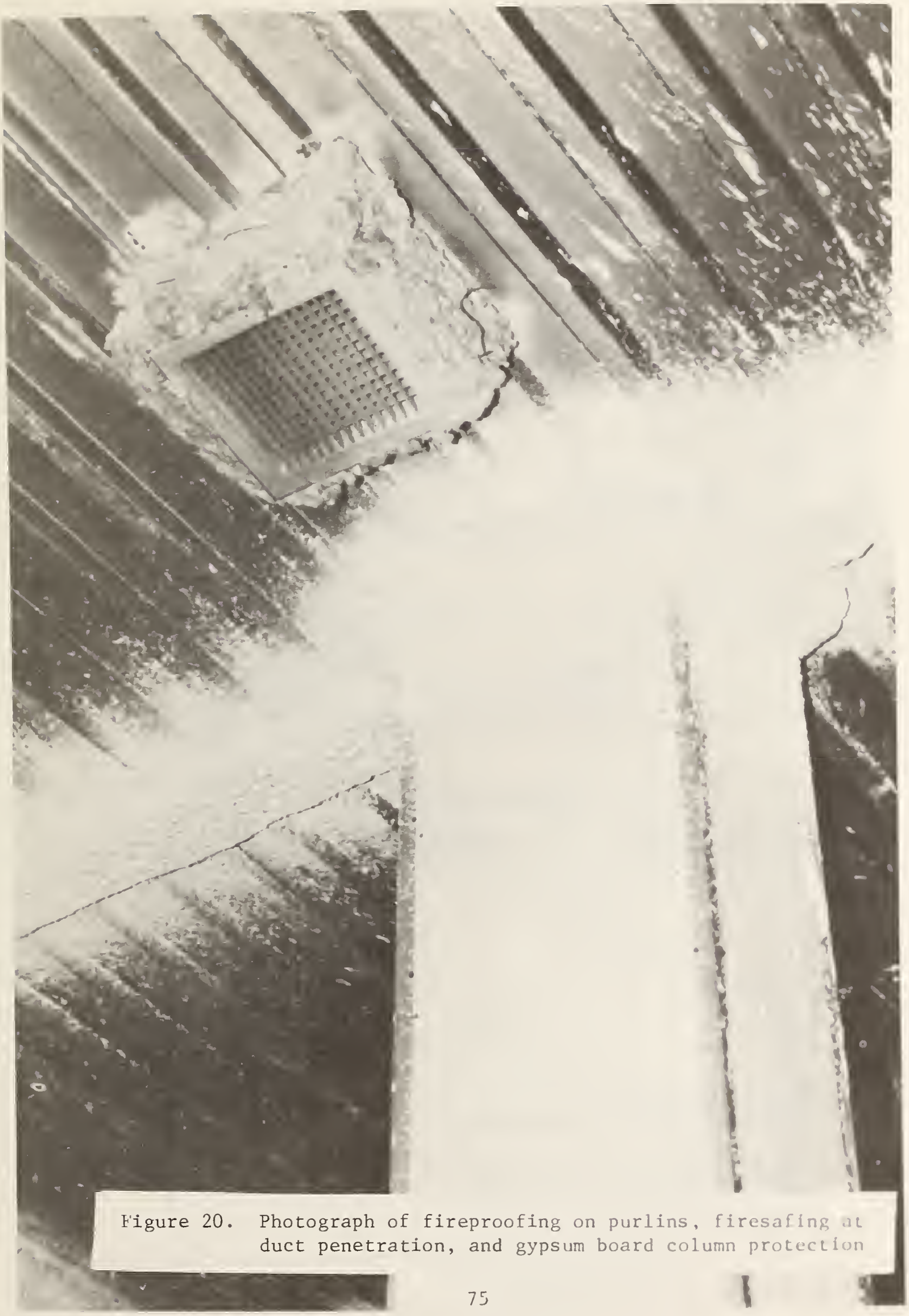


Figure 20. Photograph of fireproofing on purlins, firesafing at duct penetration, and gypsum board column protection

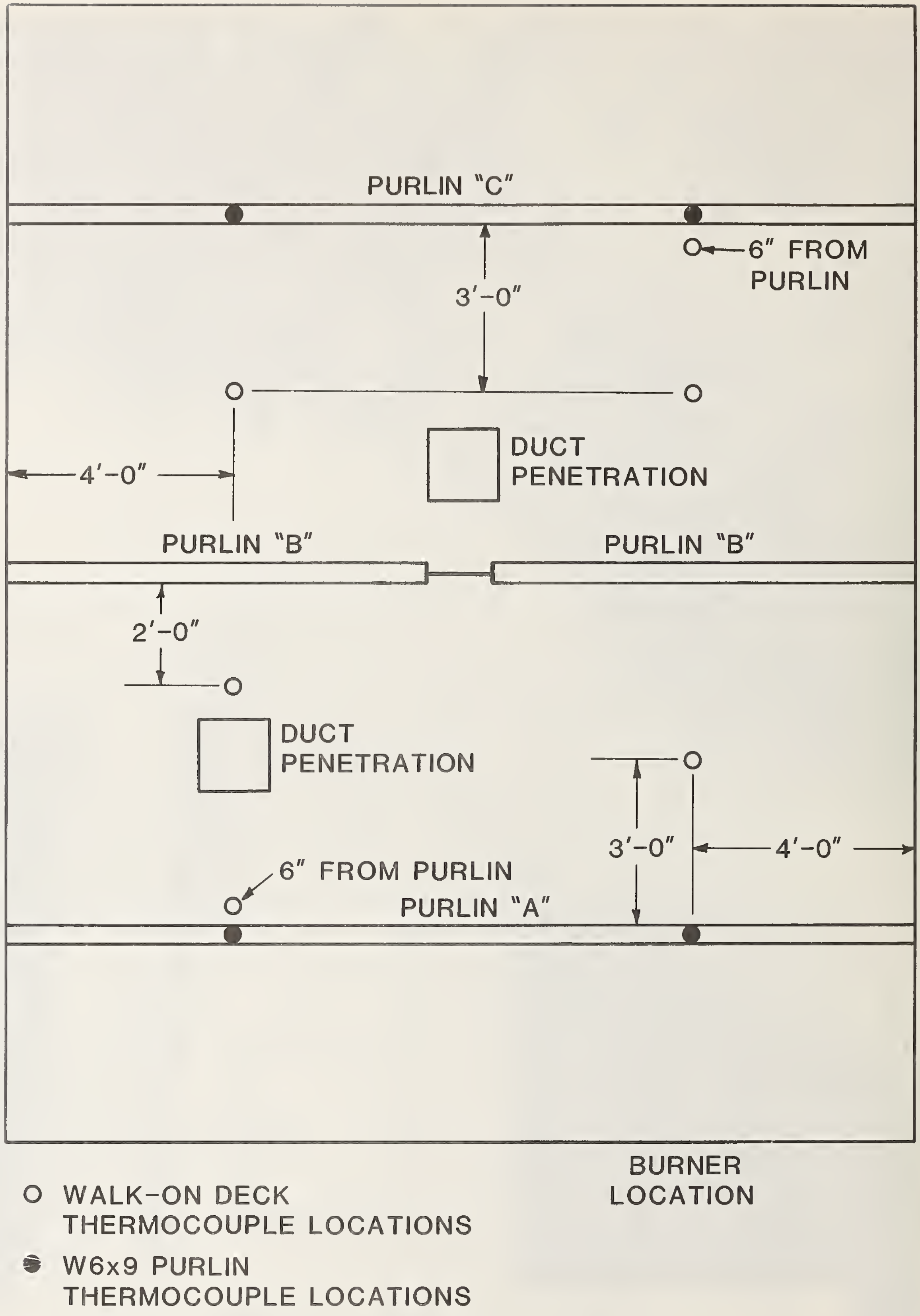


Figure 21. Locations for thermocouples used in the lightweight concrete deck system

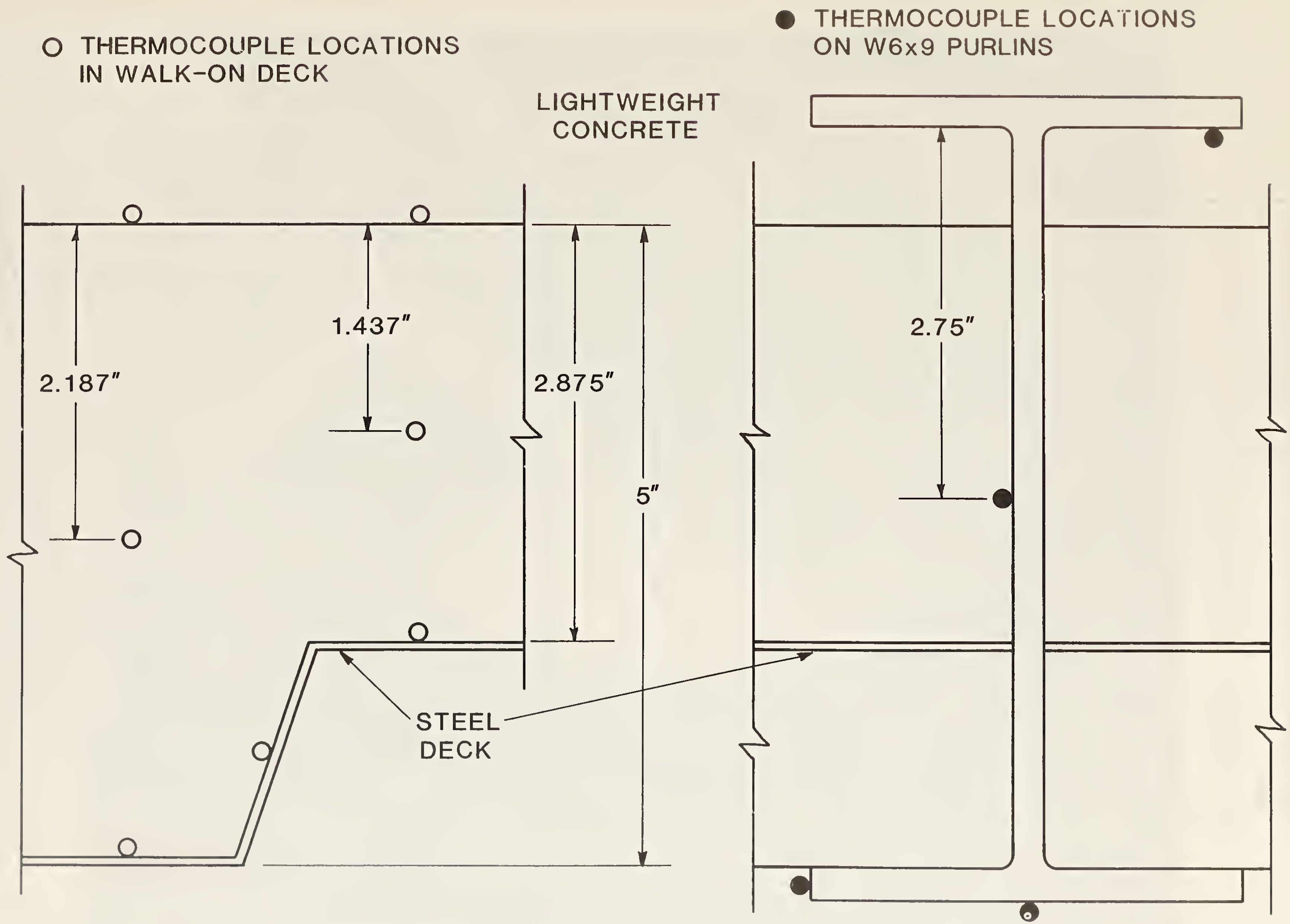


Figure 22. Arrangement of thermocouples attached to W 6x9 steel purlin supporting the walk-on deck

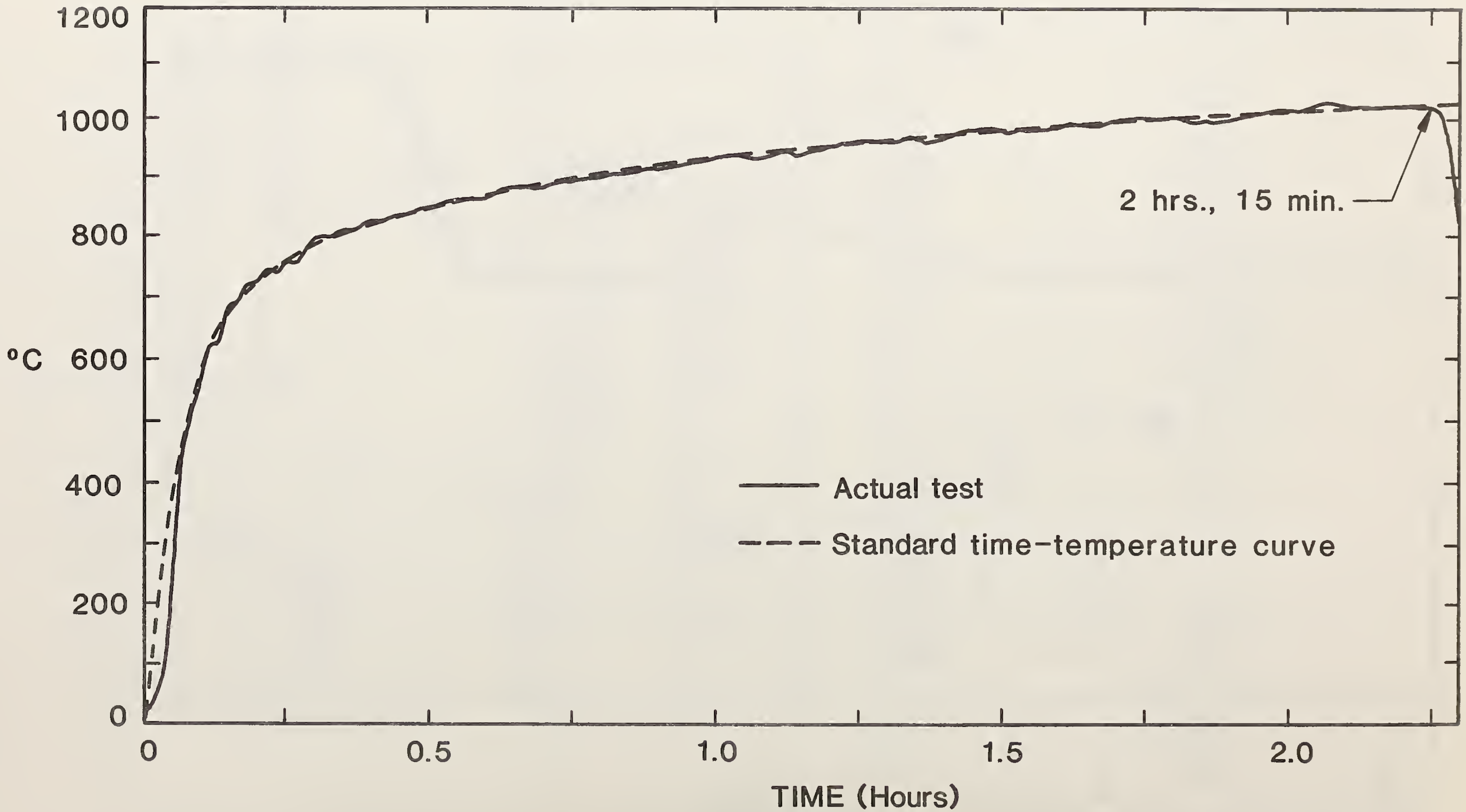


Figure 23. Chart record of average furnace temperature, test 1

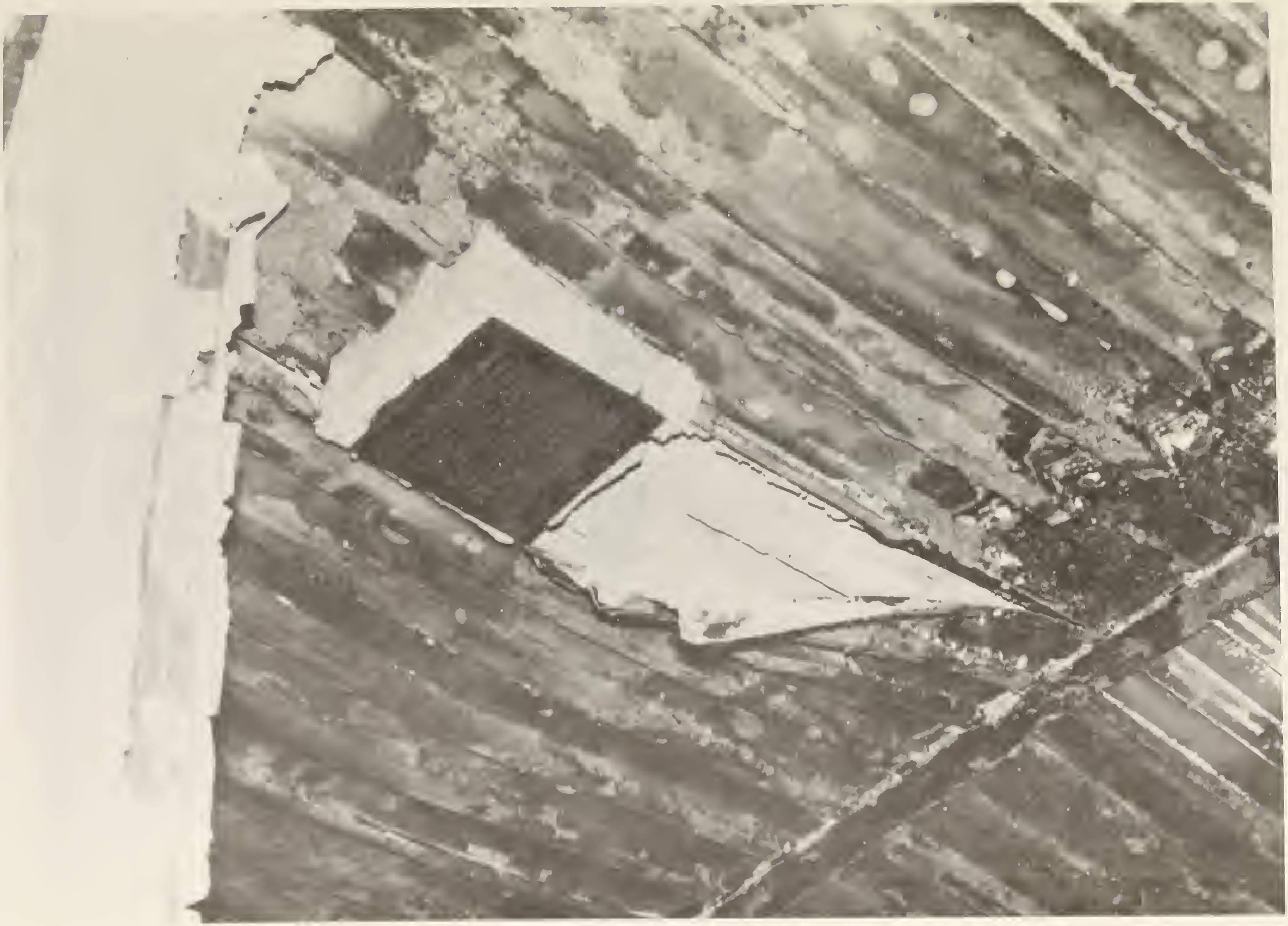


Figure 24. Photograph showing bottom of walk-on deck after test 1

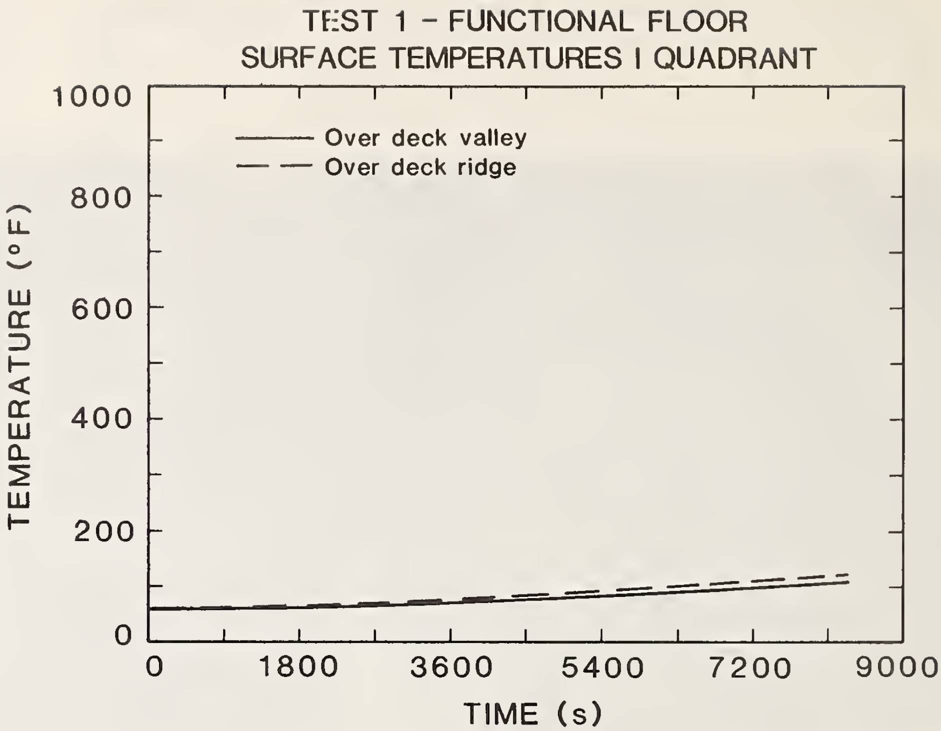


Figure 25. Functional floor surface temperatures quadrant I, test 1

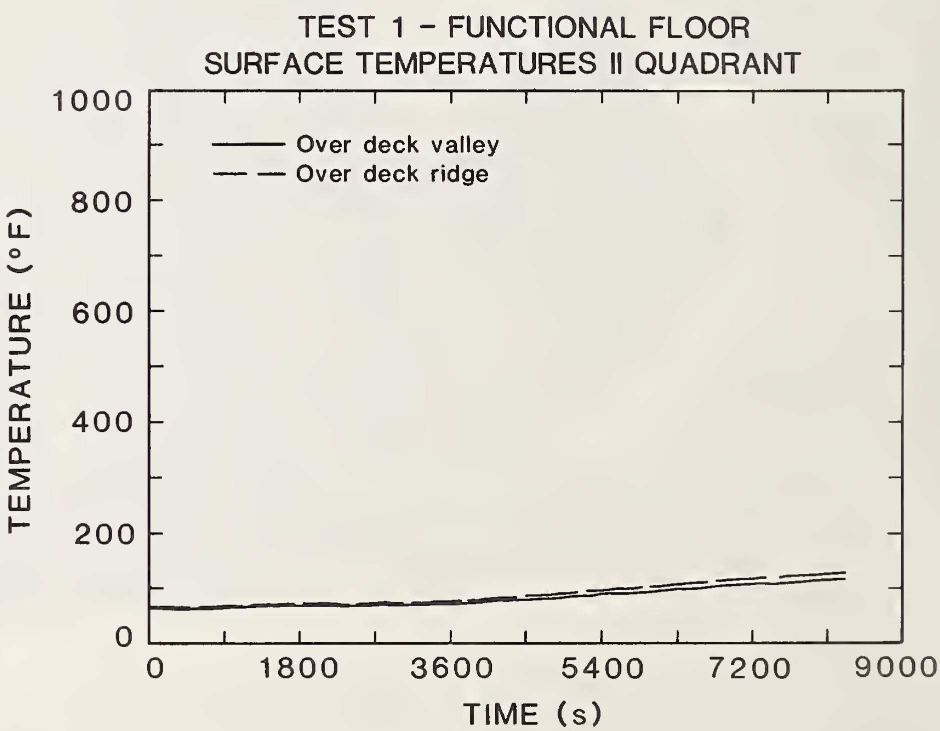


Figure 26. Functional floor surface temperatures quadrant II, test 1

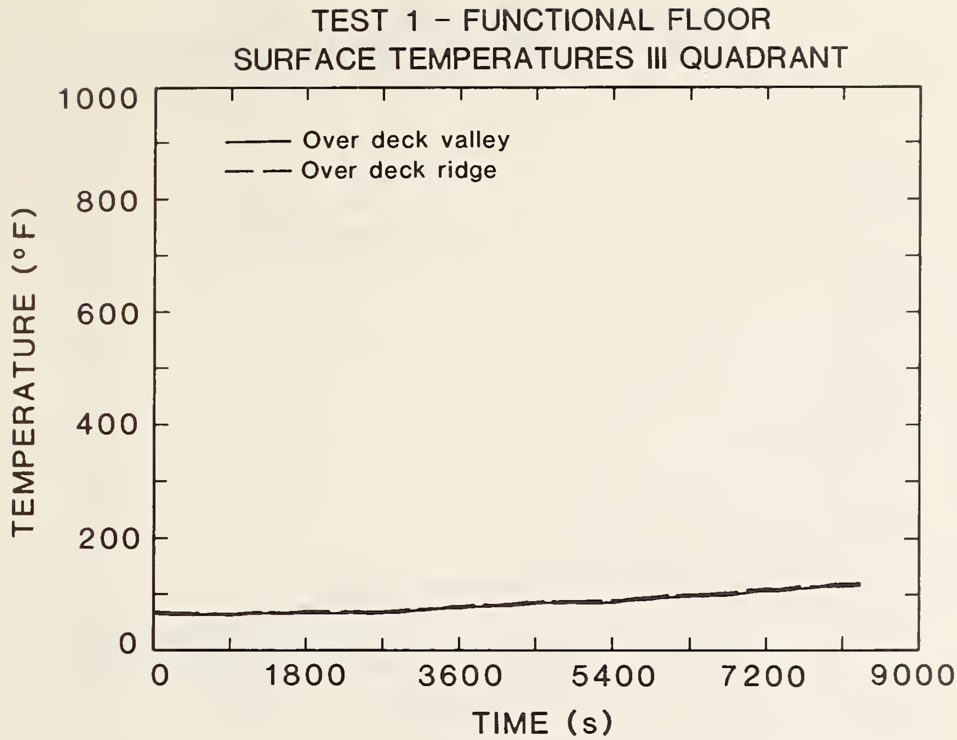


Figure 27. Functional floor surface temperatures quadrant III, test 1

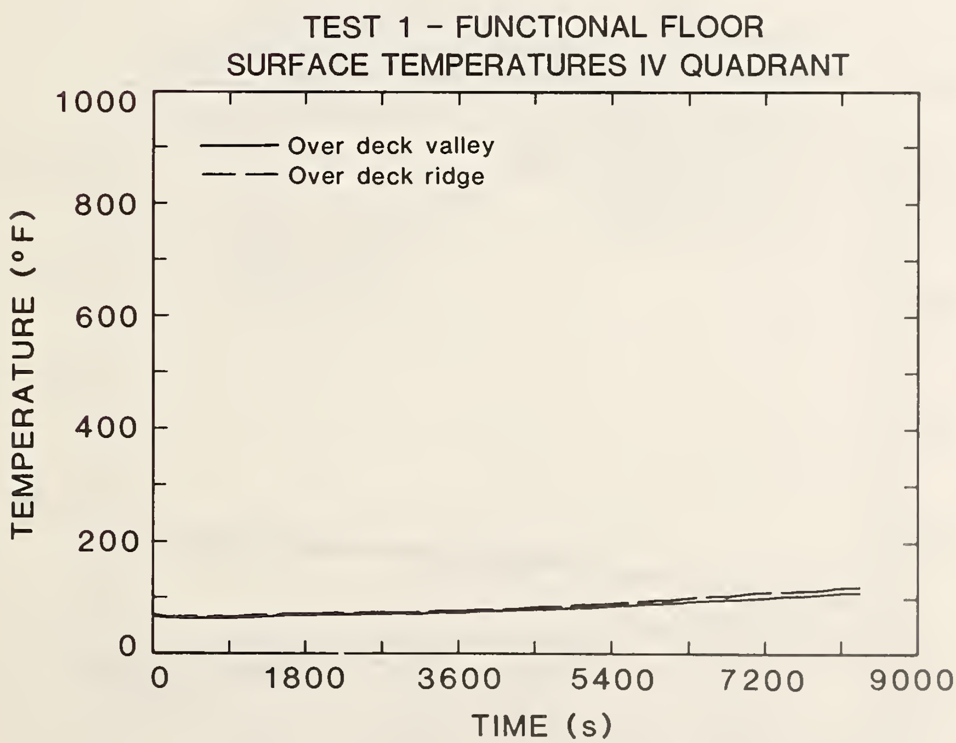


Figure 28. Functional floor surface temperatures quadrant IV, test 1

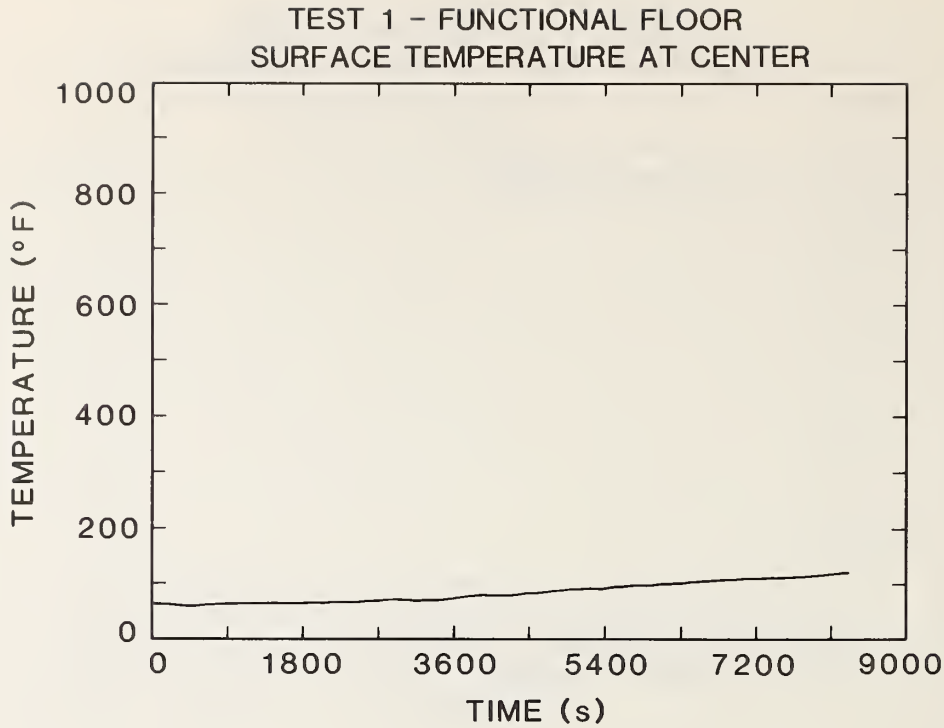


Figure 29. Functional floor surface temperature center of test bay, test 1

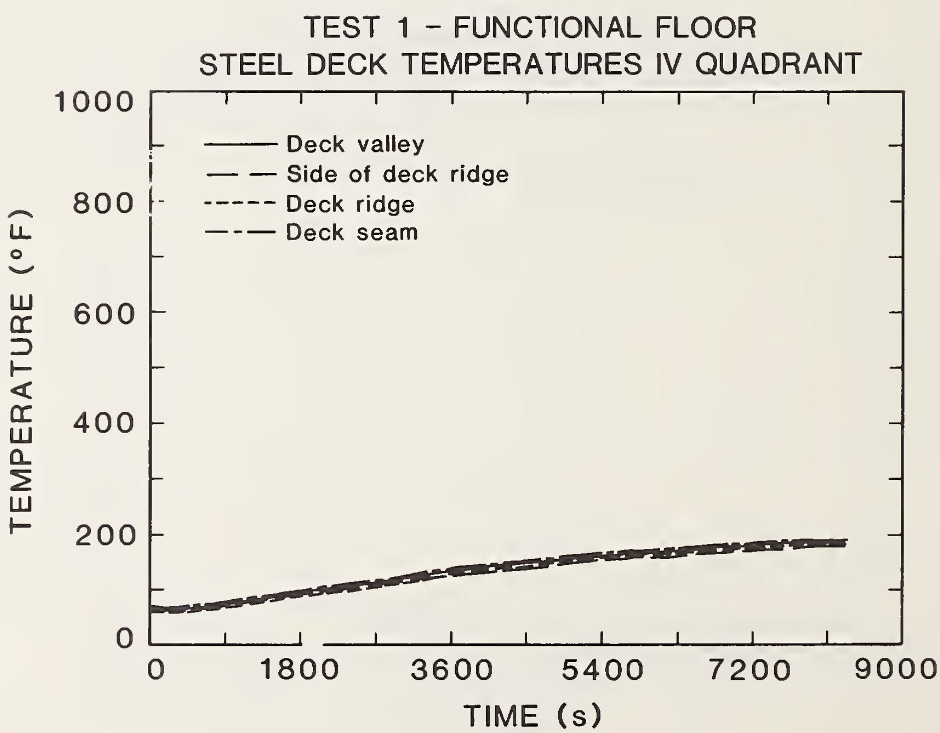


Figure 30. Functional floor steel deck temperatures quadrant IV, test 1

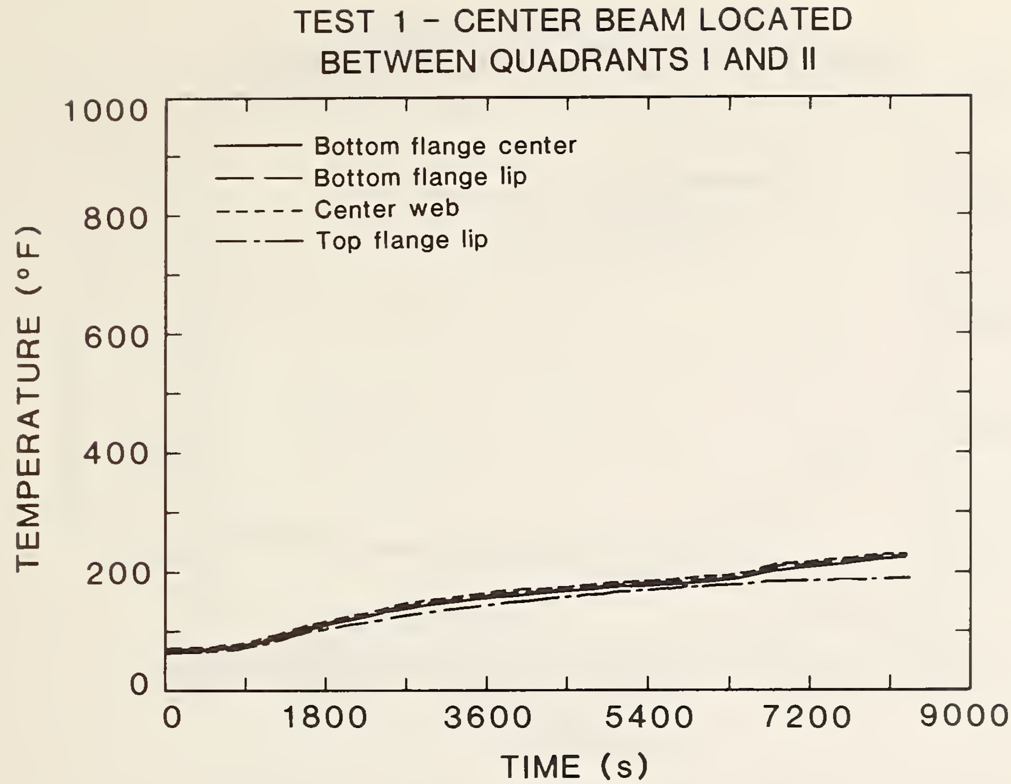


Figure 31. Temperature for center beam supporting the functional floor, center measurement point between quadrants I and II, test 1

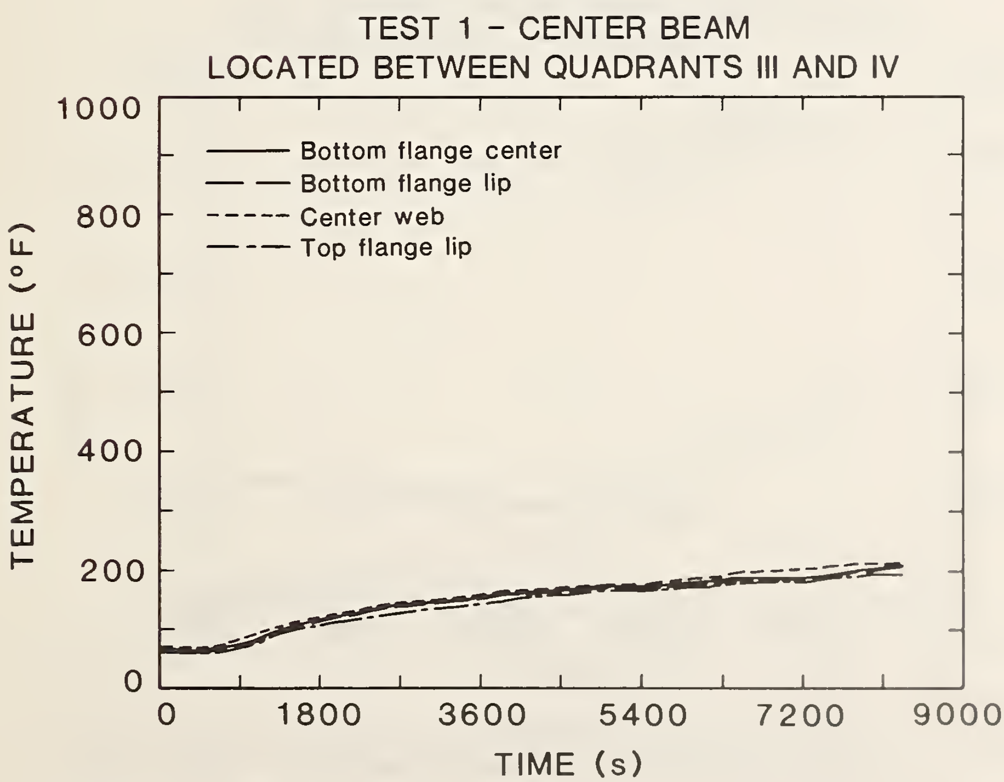


Figure 32. Temperatures for center beam supporting the functional floor, center measurement point between quadrants III and IV, test 1

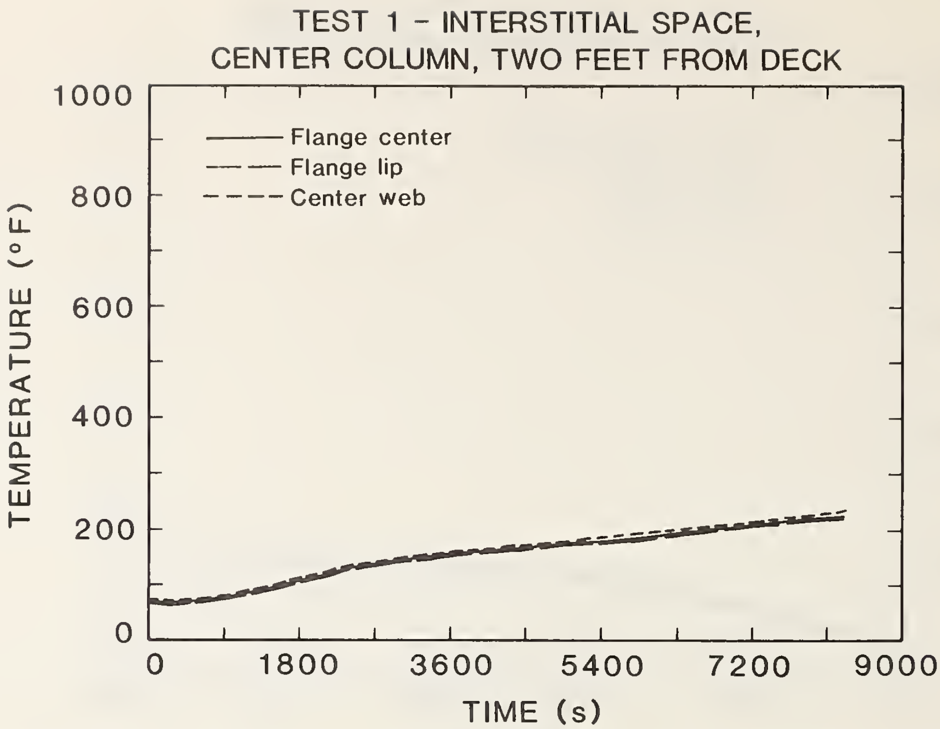


Figure 33. Center column temperatures in interstitial space at measurement point two feet above walk-on deck, test 1

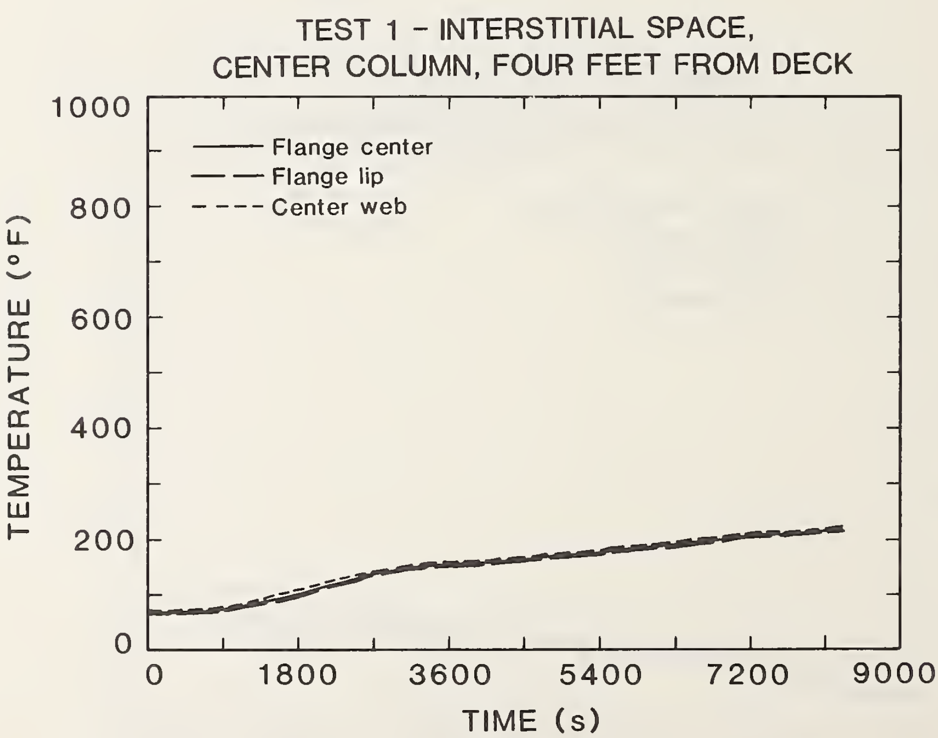


Figure 34. Center column temperatures in interstitial space at measurement point four feet above walk-on deck, test 1

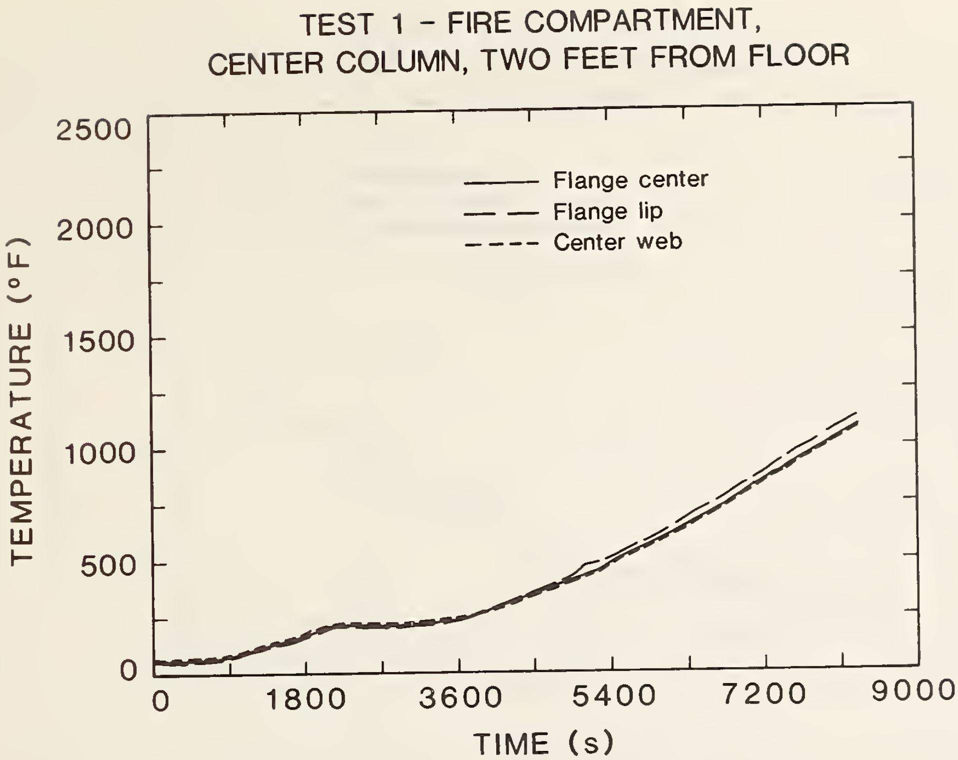


Figure 35. Column temperatures in furnace compartment two feet up from floor, test 1

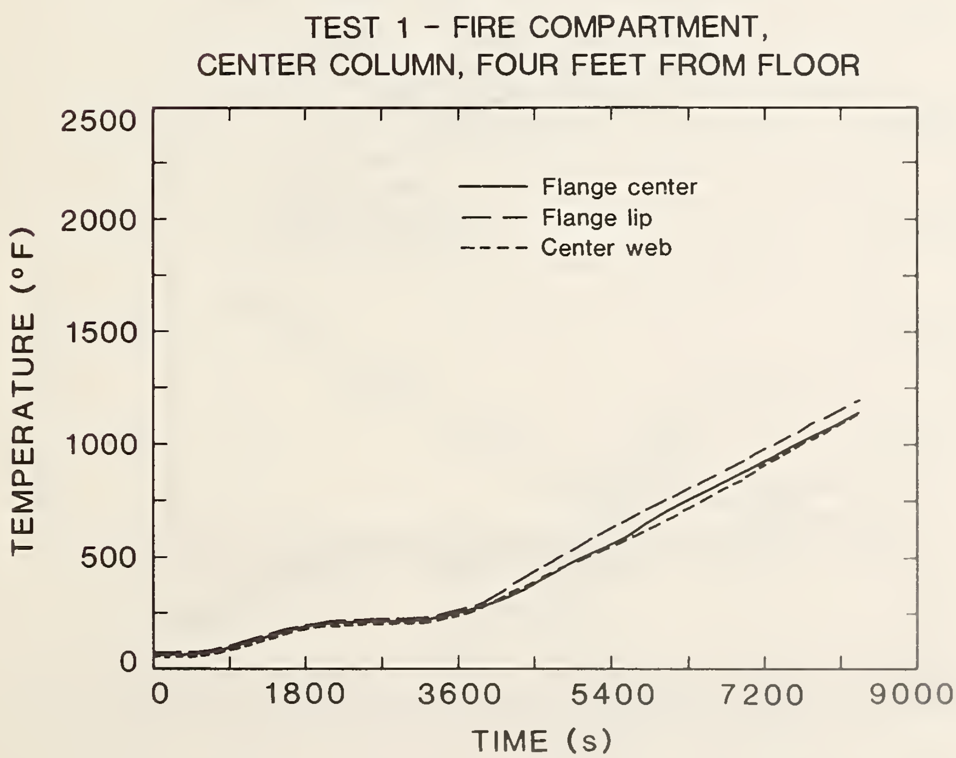


Figure 36. Column temperatures in furnace compartment four feet up from floor, test 1

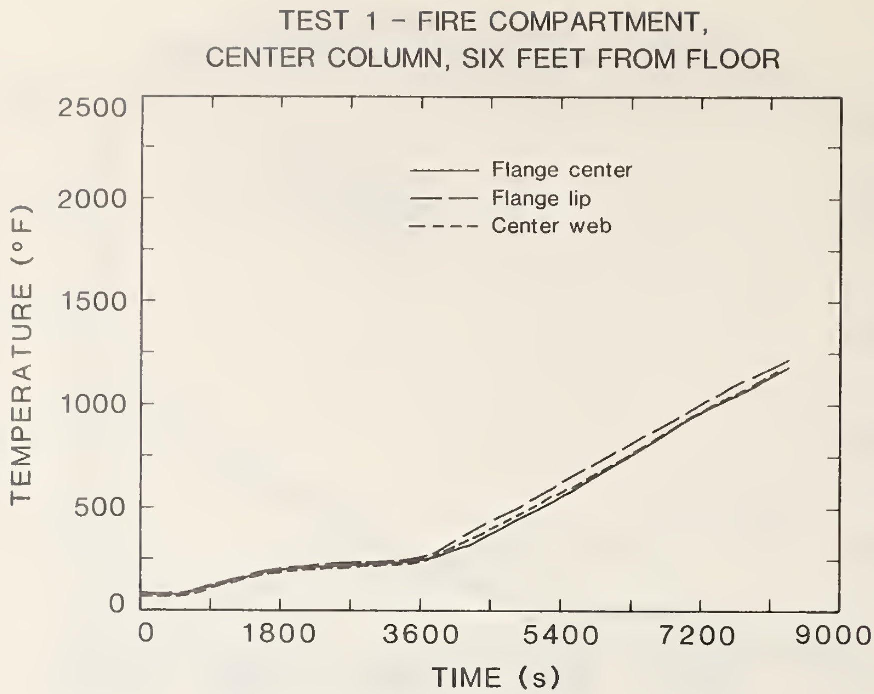


Figure 37. Column temperatures in furnace compartment six feet up from floor, test 1

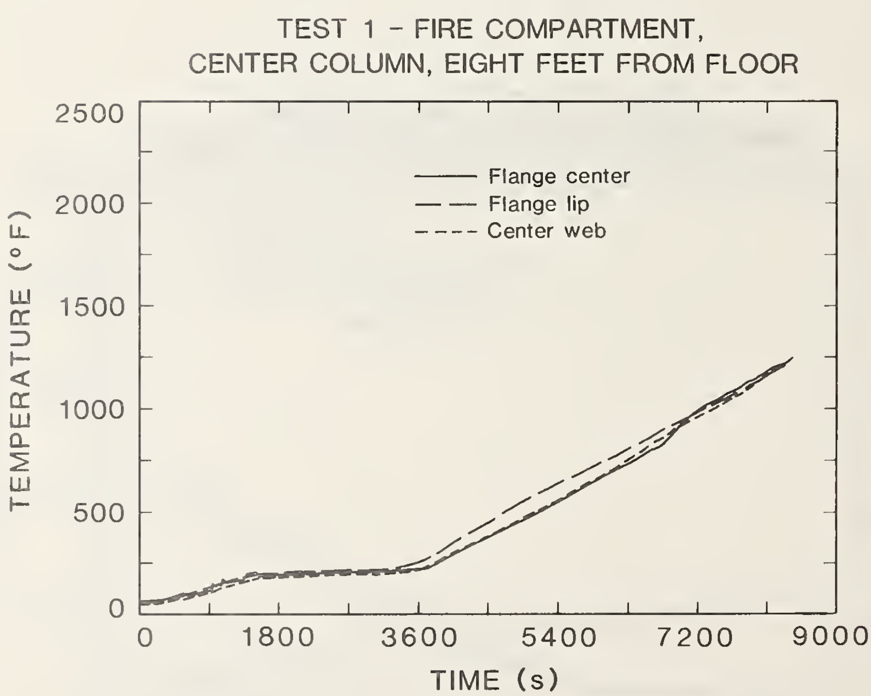


Figure 38. Column temperatures in furnace compartment eight feet up from floor, test 1

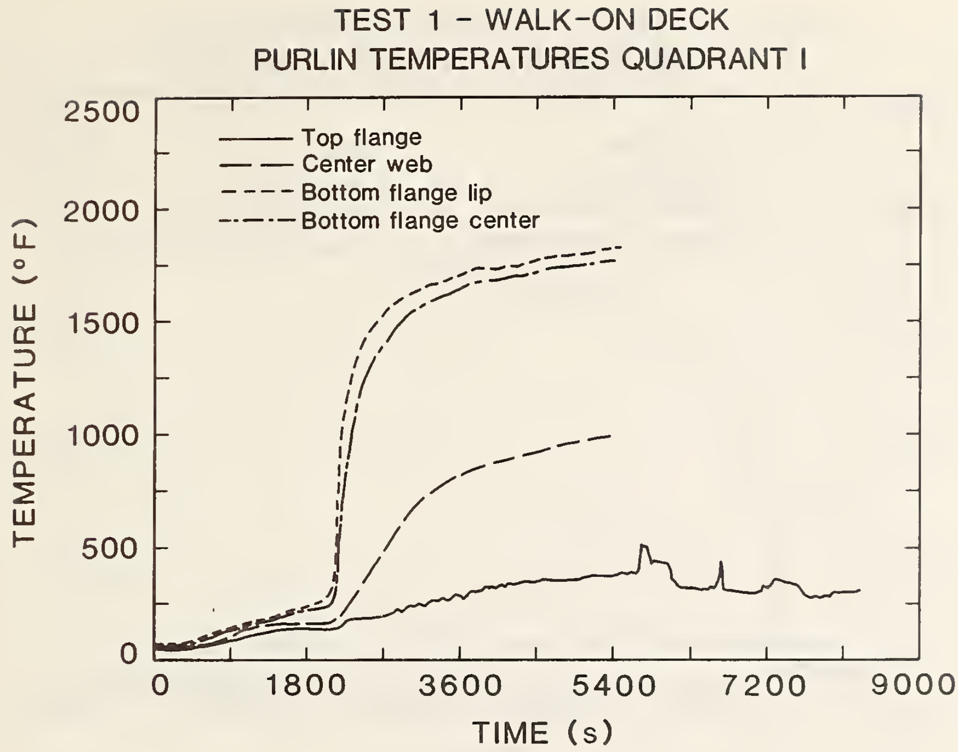


Figure 39. Walk-on deck purlin temperatures quadrant I, test 1

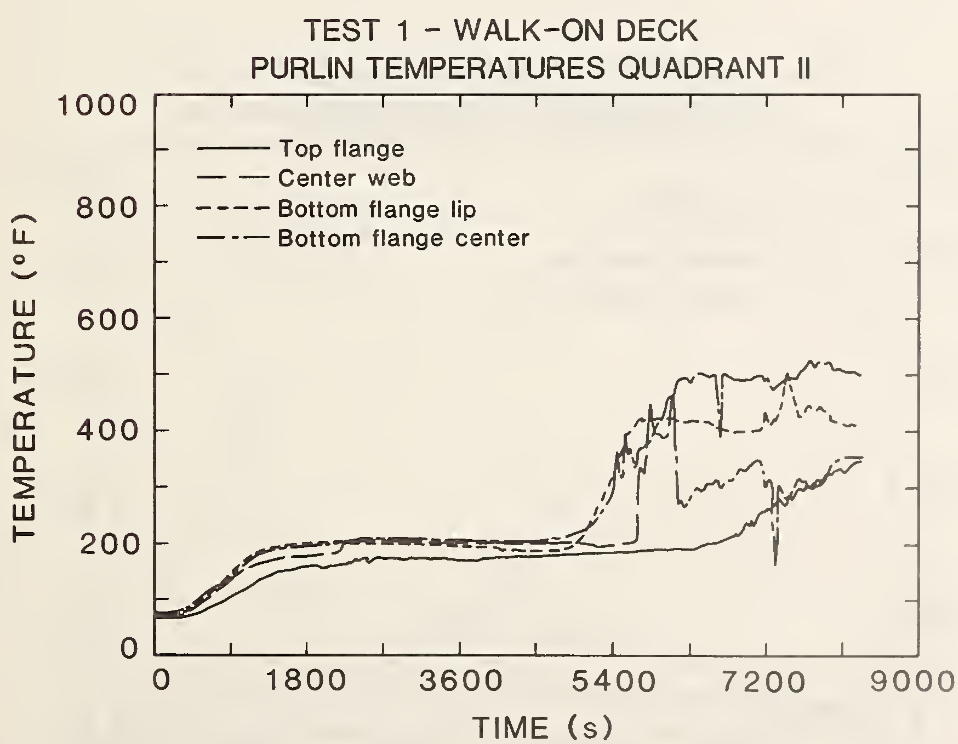


Figure 40. Walk-on deck purlin temperatures quadrant II, test 1

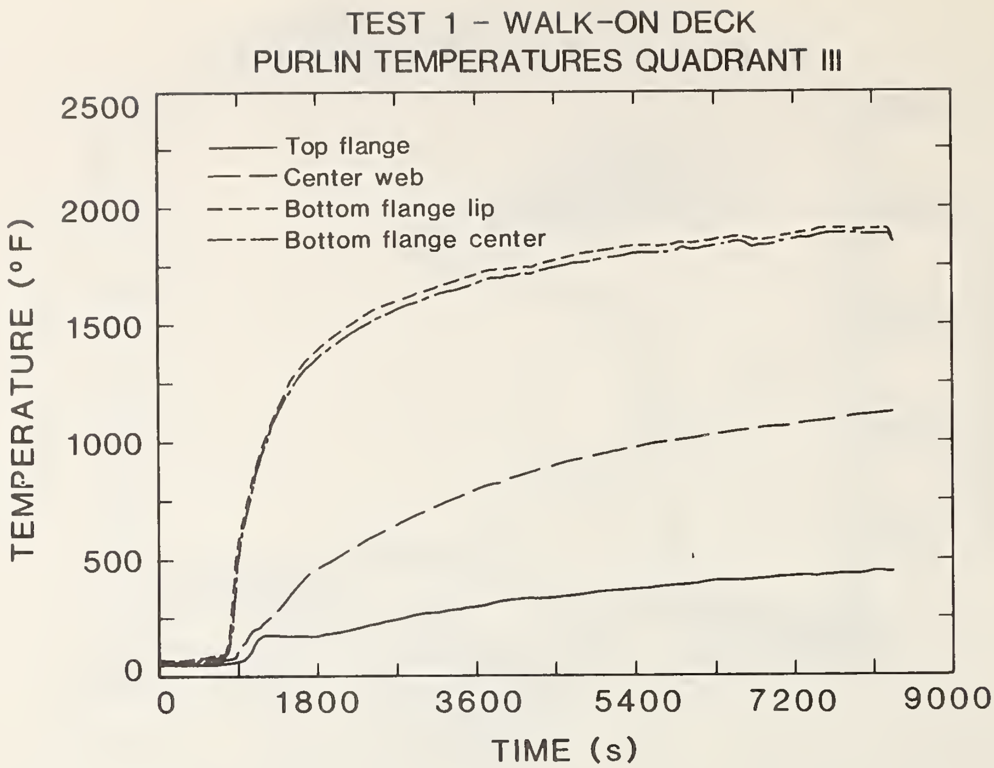


Figure 41. Walk-on deck purlin temperatures quadrant III, test 1

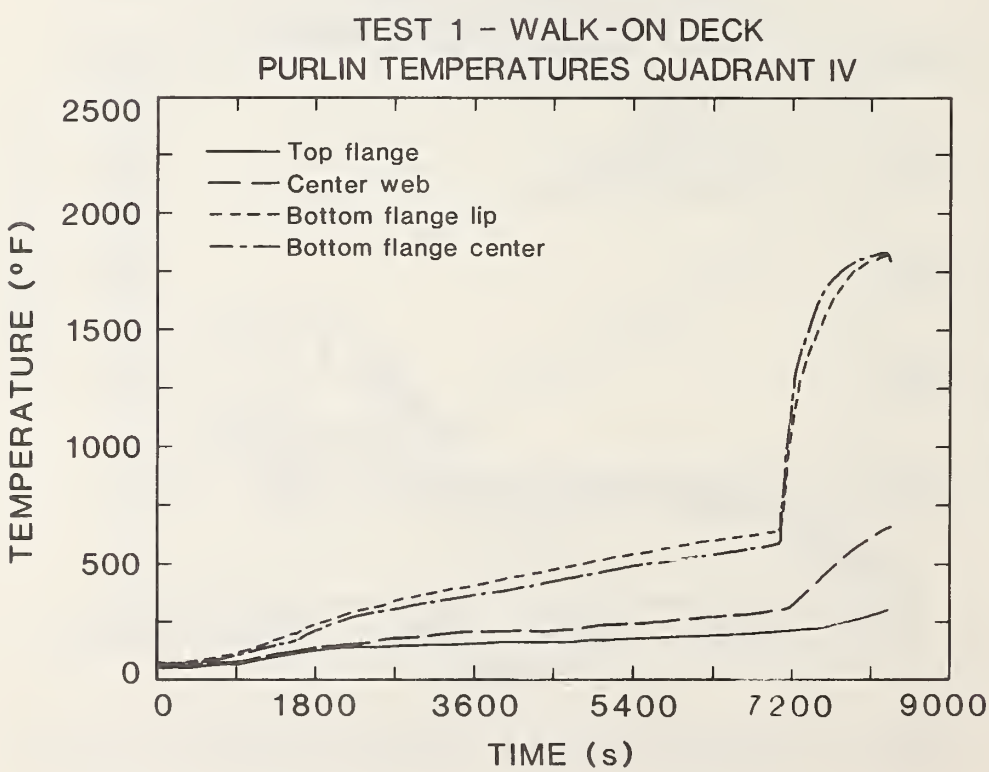


Figure 42. Walk-on deck purlin temperatures quadrant IV, test 1

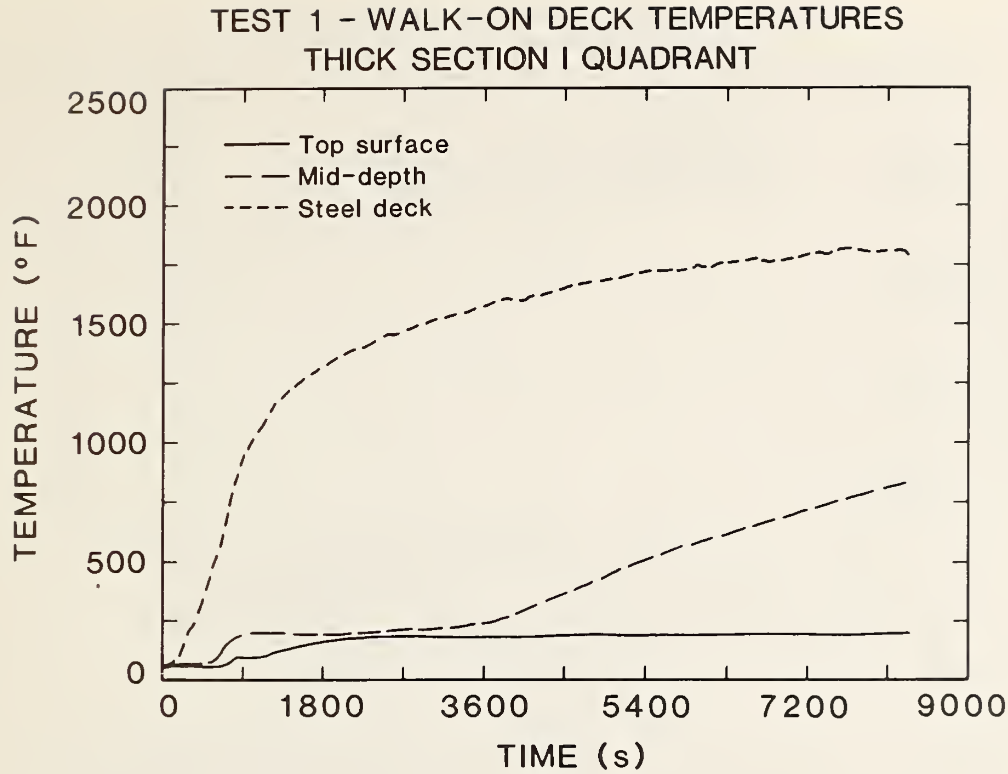


Figure 43. Walk-on deck temperatures thick section quadrant I, test 1

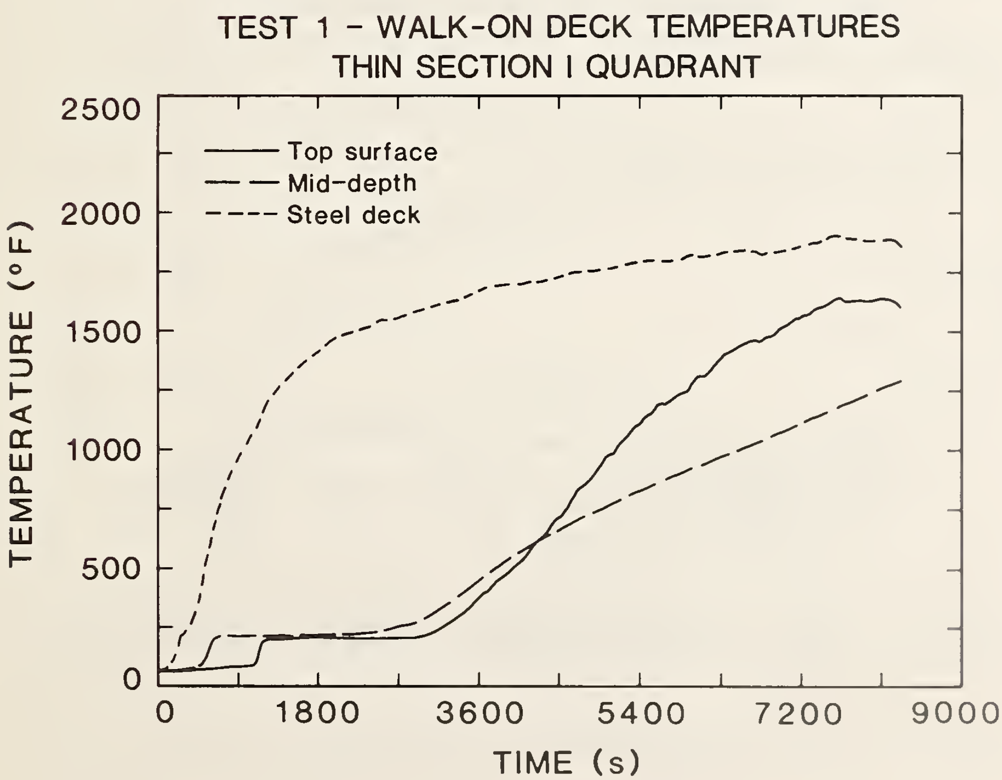


Figure 44. Walk-on deck temperatures thin section quadrant I, test 1

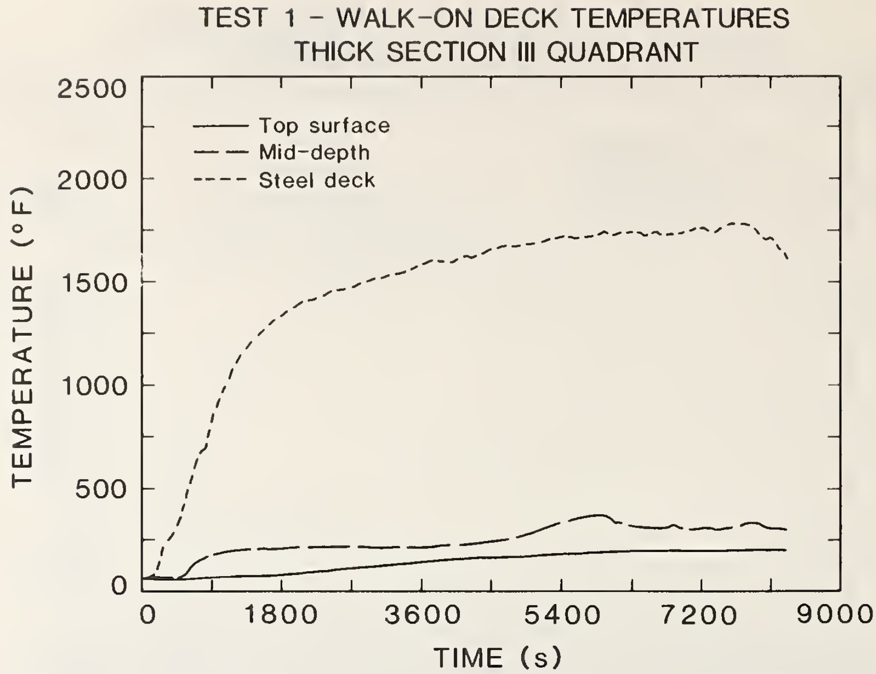


Figure 45. Walk-on deck temperatures thick section quadrant III, test 1

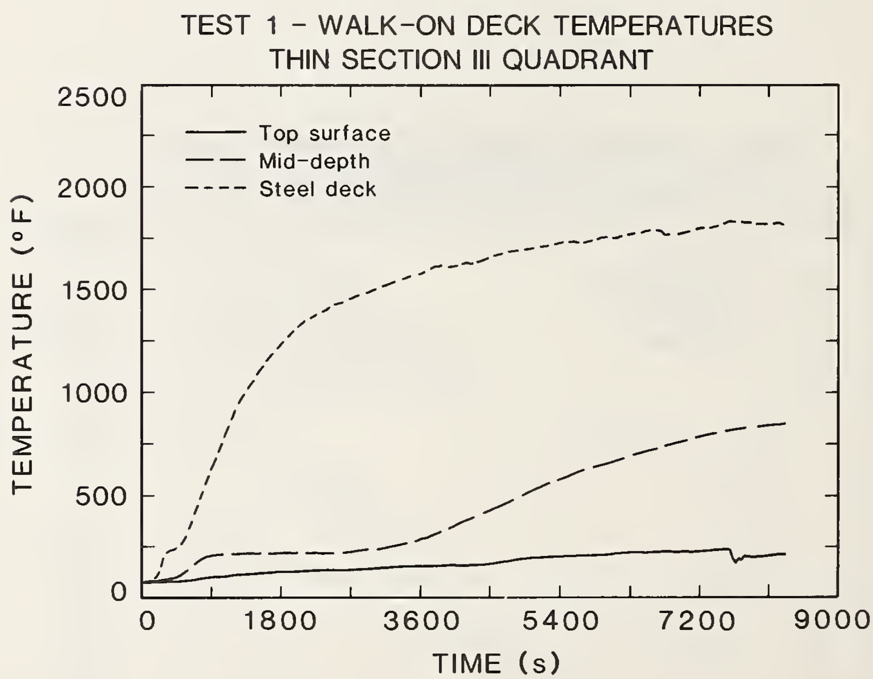


Figure 46. Walk-on deck temperatures thin section quadrant III, test 1

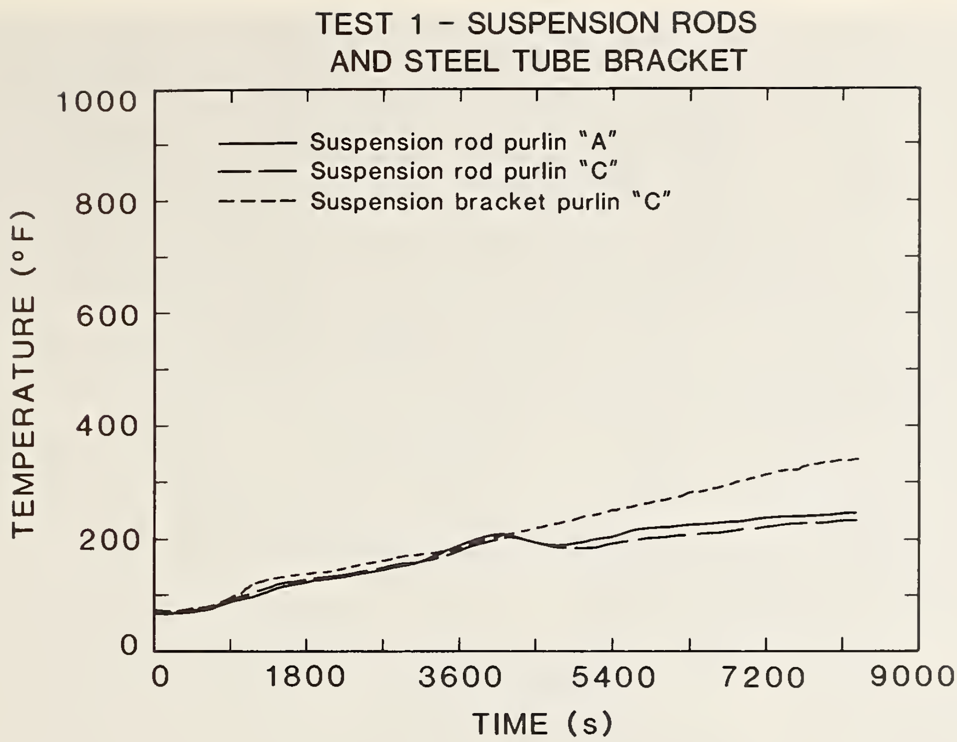


Figure 47. Temperatures for suspension rods and steel tube bracket, test 1

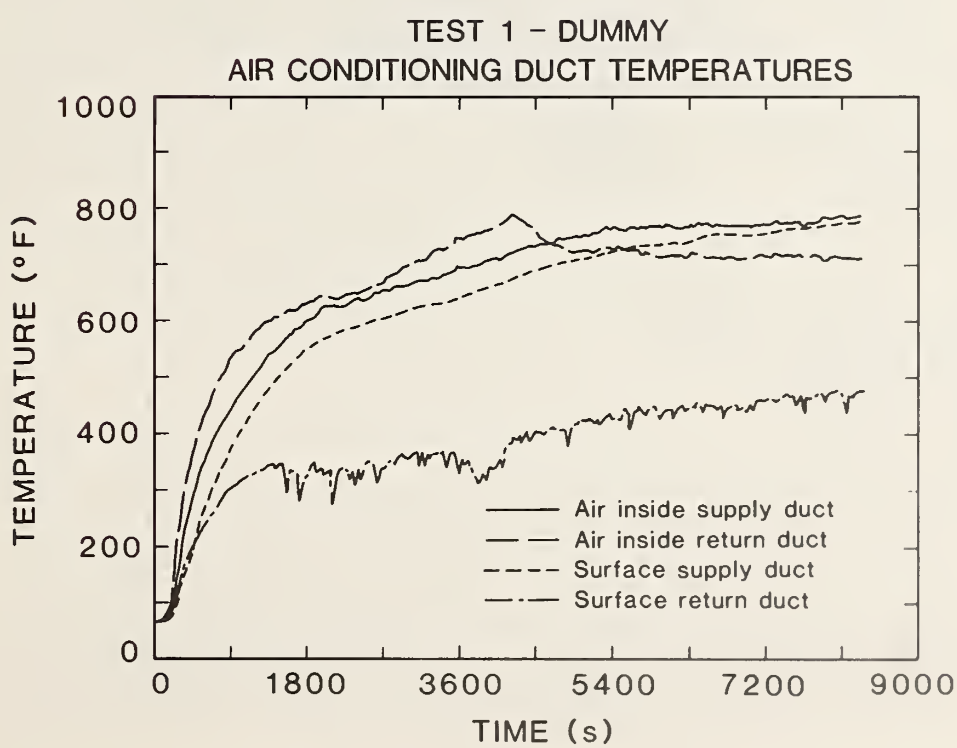


Figure 48. Dummy air conditioning duct temperatures, test 1

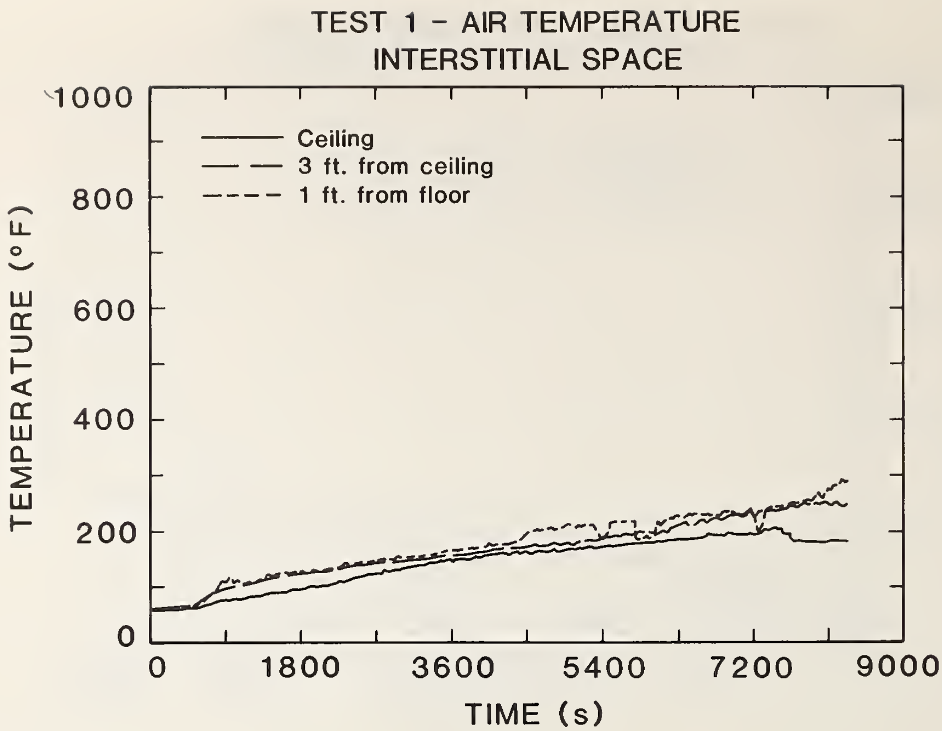


Figure 49. Interstitial space air temperatures, test 1

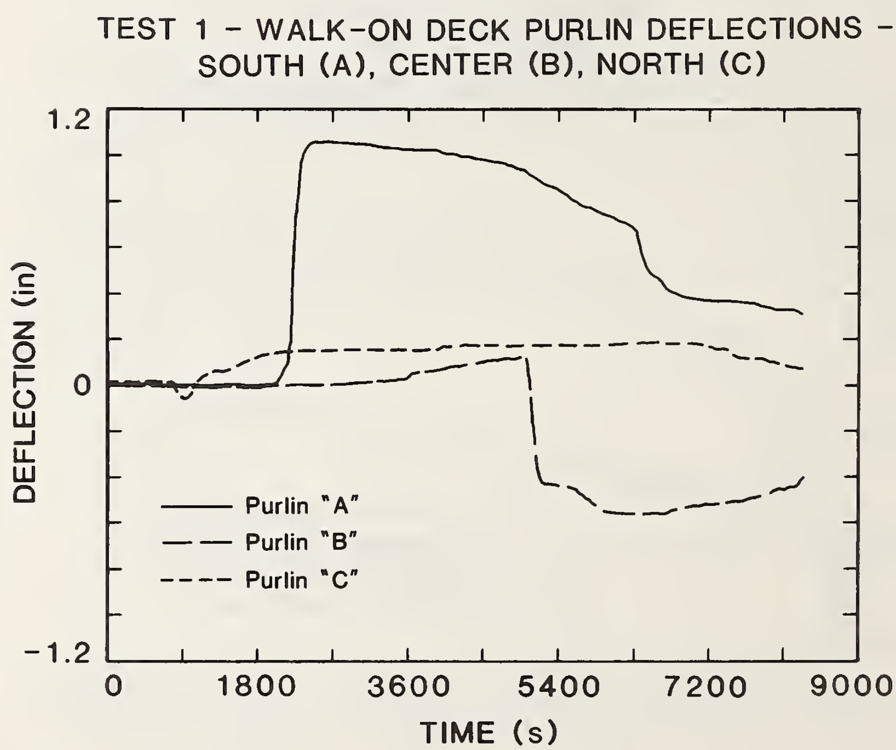


Figure 50. Walk-on deck purlin deflections, test 1

Figure 51. Photograph showing permanent upward set of suspended purlin, test 1

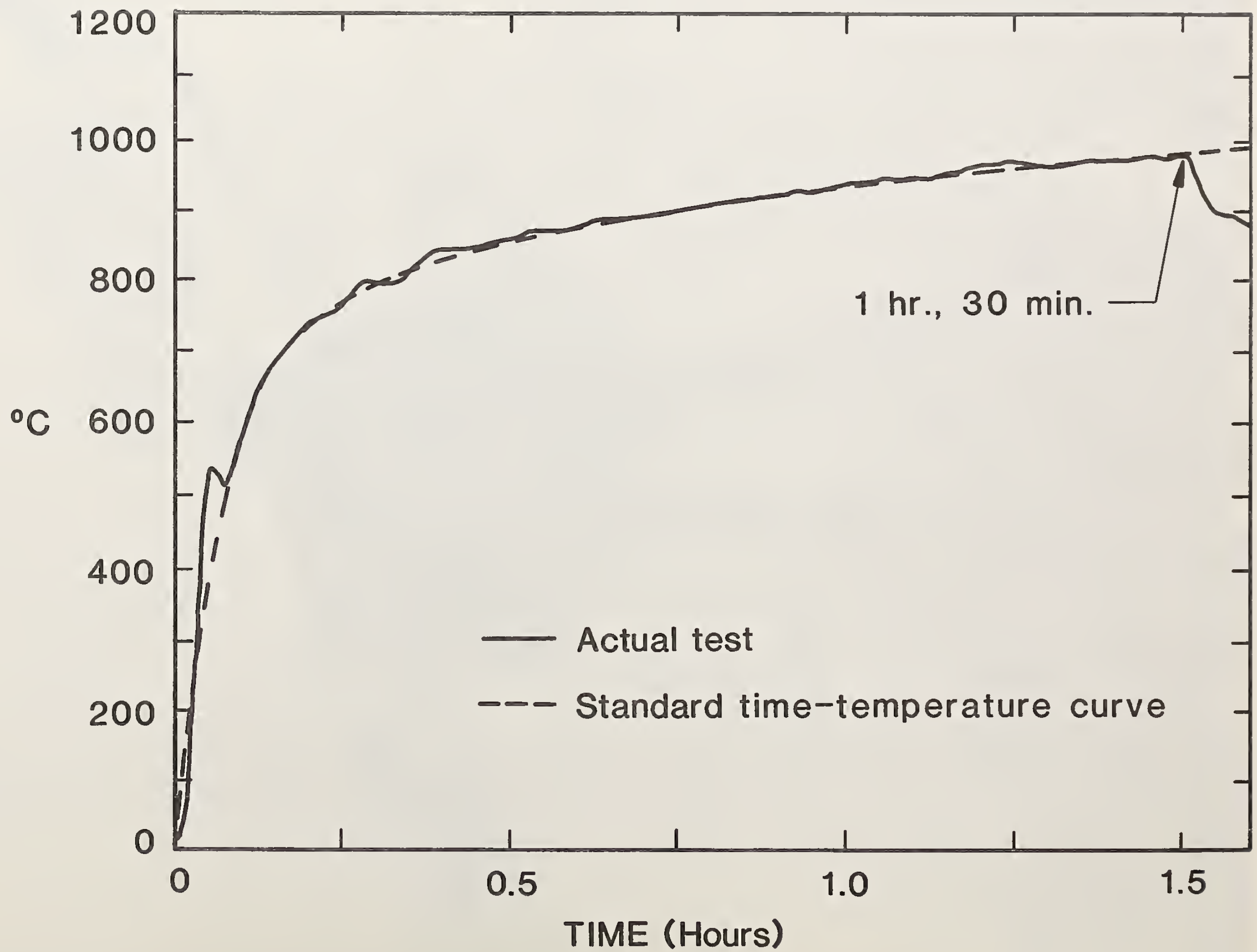


Figure 52. Chart record of average furnace temperature, test 2

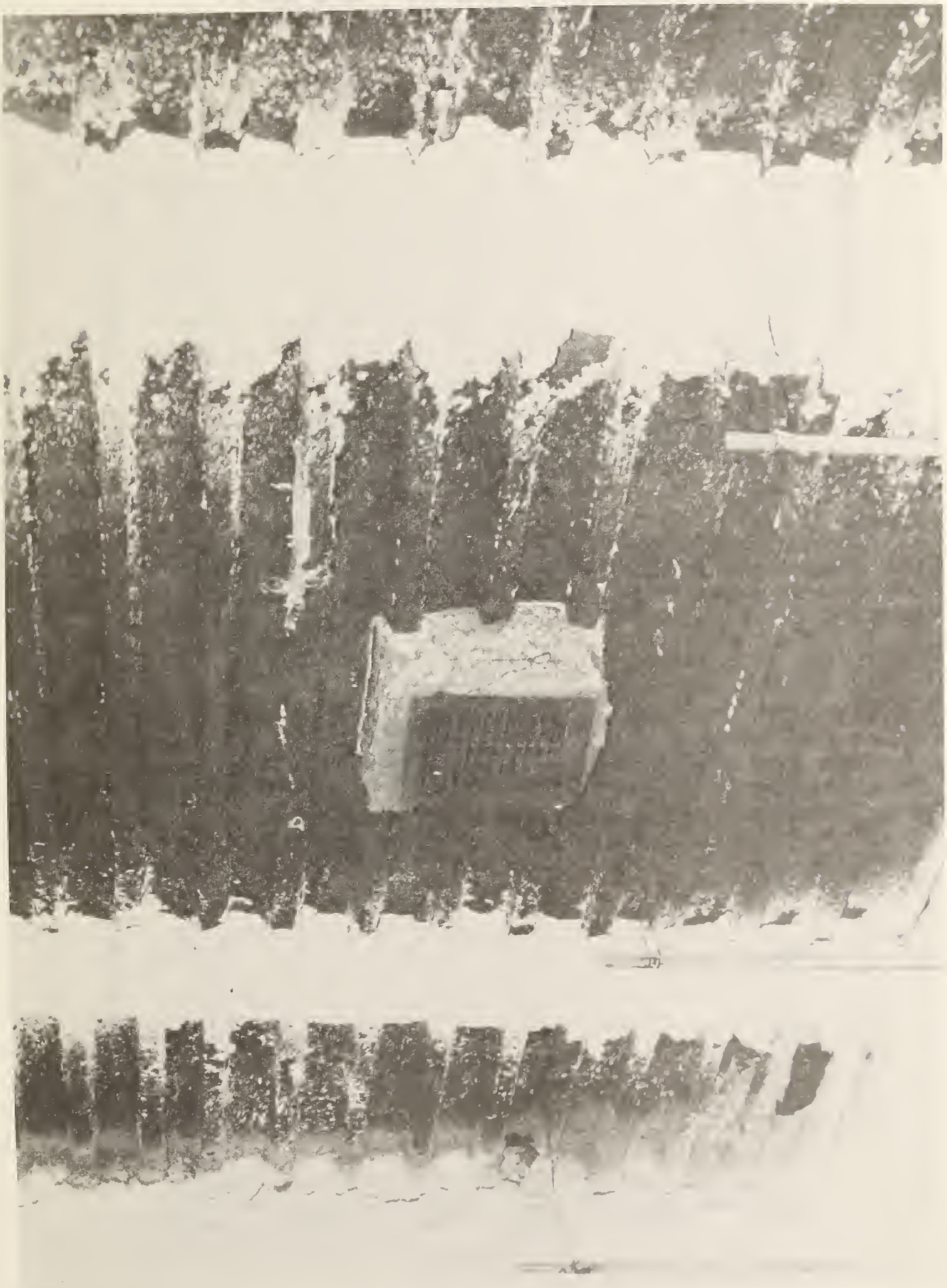


Figure 53. Photograph showing bottom of walk-on deck after test 2

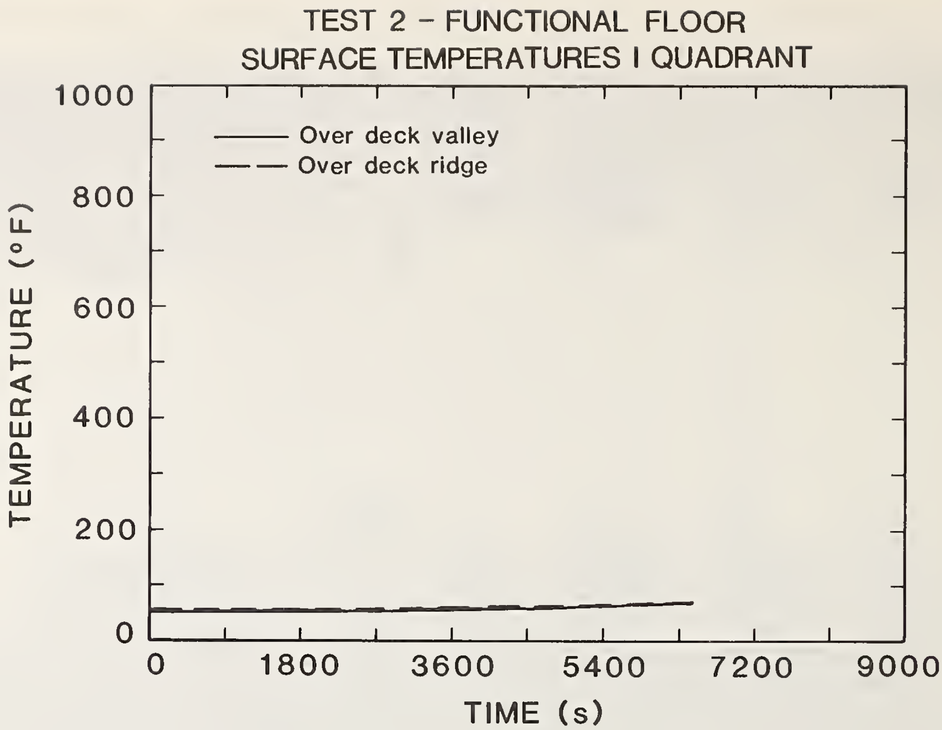


Figure 54. Functional floor surface temperatures quadrant I, test 2

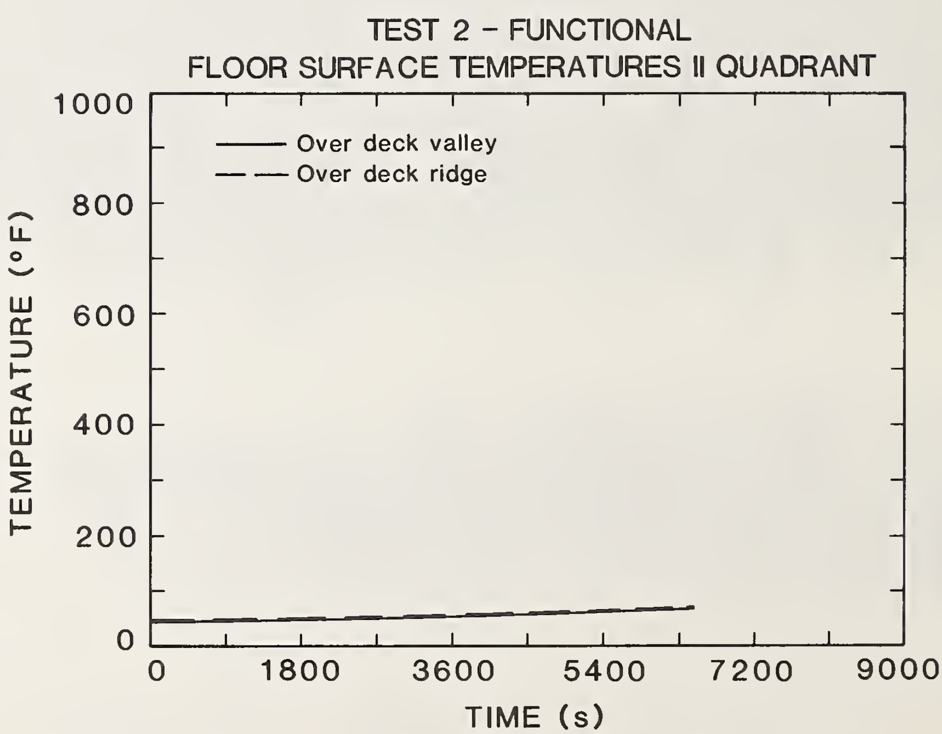


Figure 55. Functional floor surface temperature quadrant II, test 2

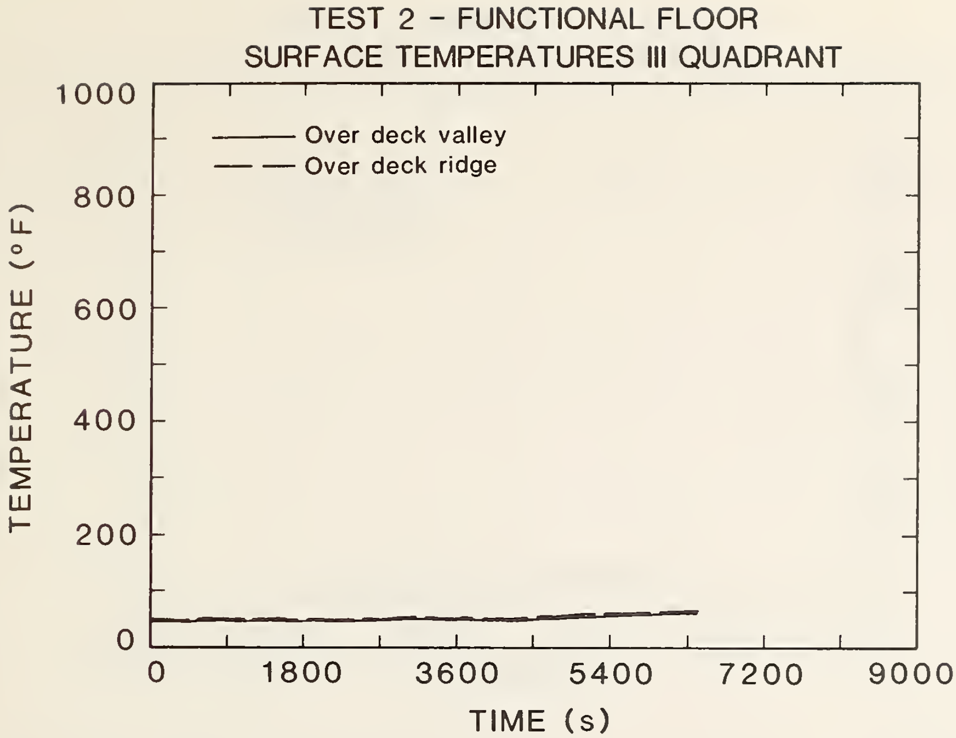


Figure 56. Functional floor surface temperature quadrant III, test 2

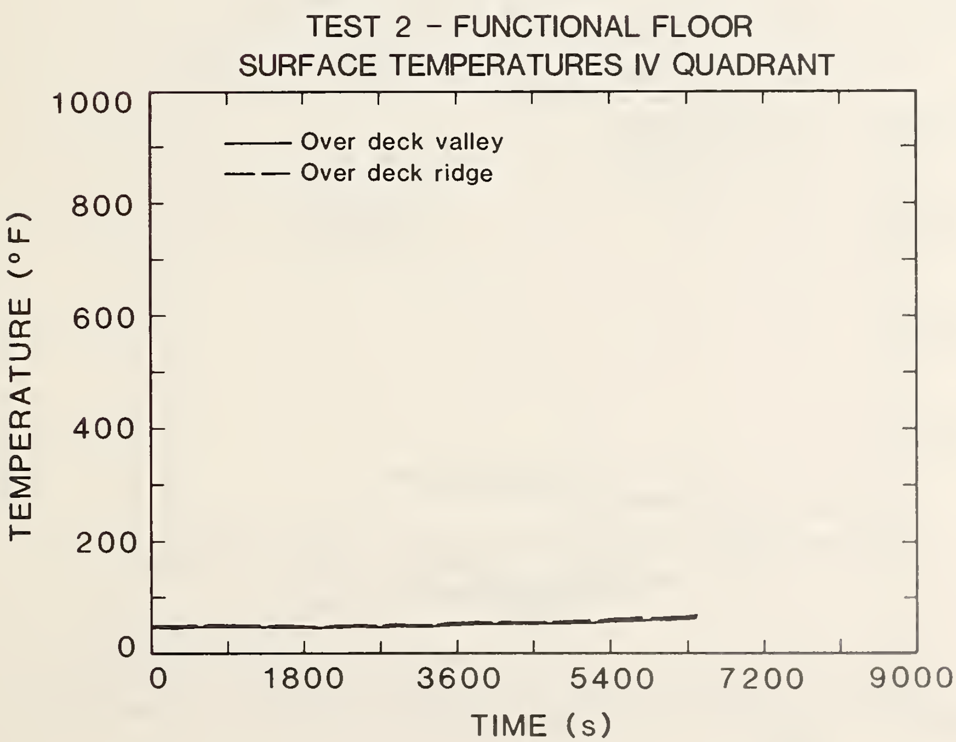


Figure 57. Functional floor surface temperature quadrant IV, test 2

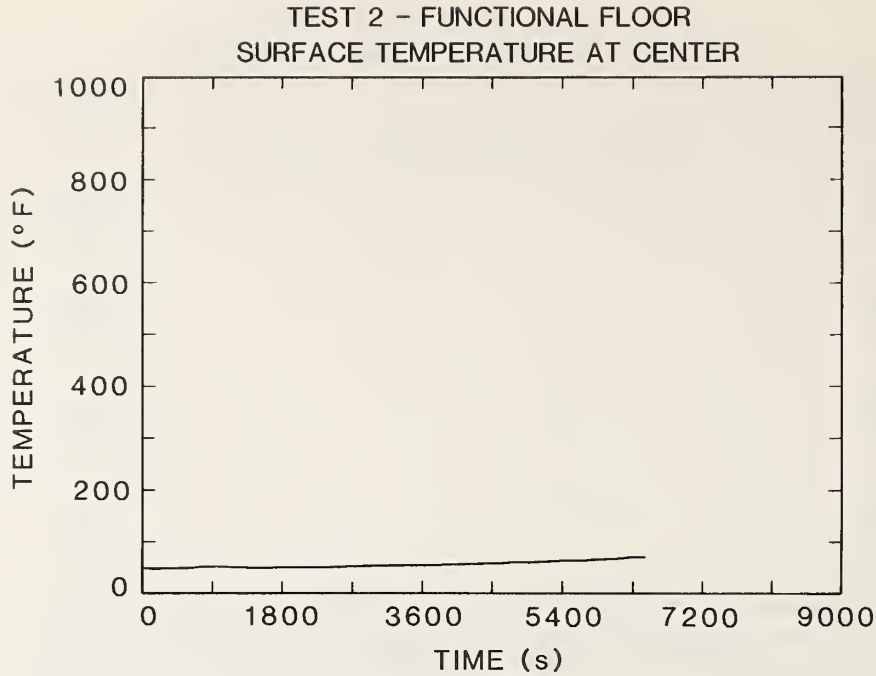


Figure 58. Functional floor surface temperature center of test bay, test 2

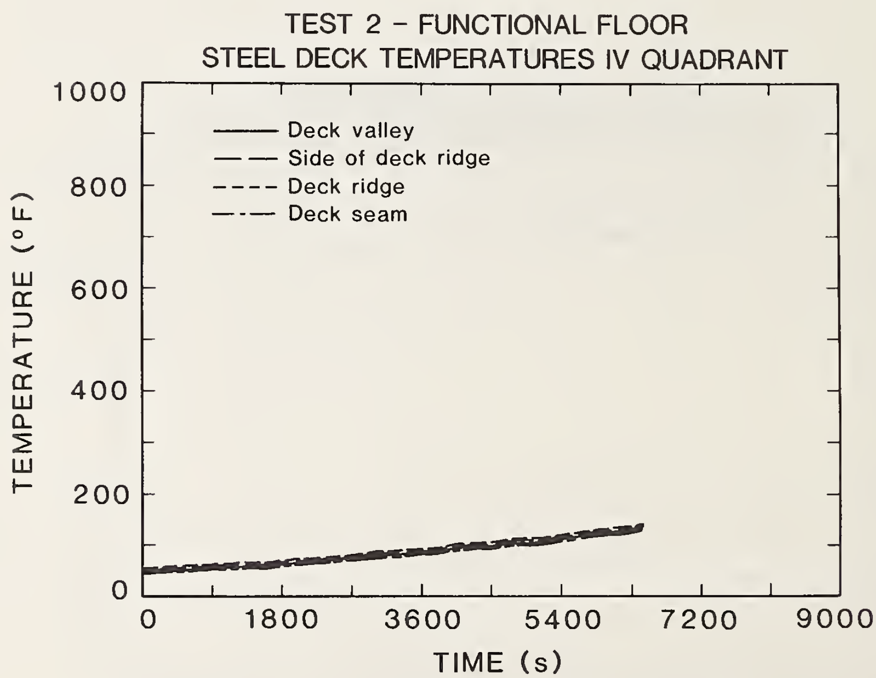


Figure 59. Functional floor steel deck temperatures quadrant IV, test 2

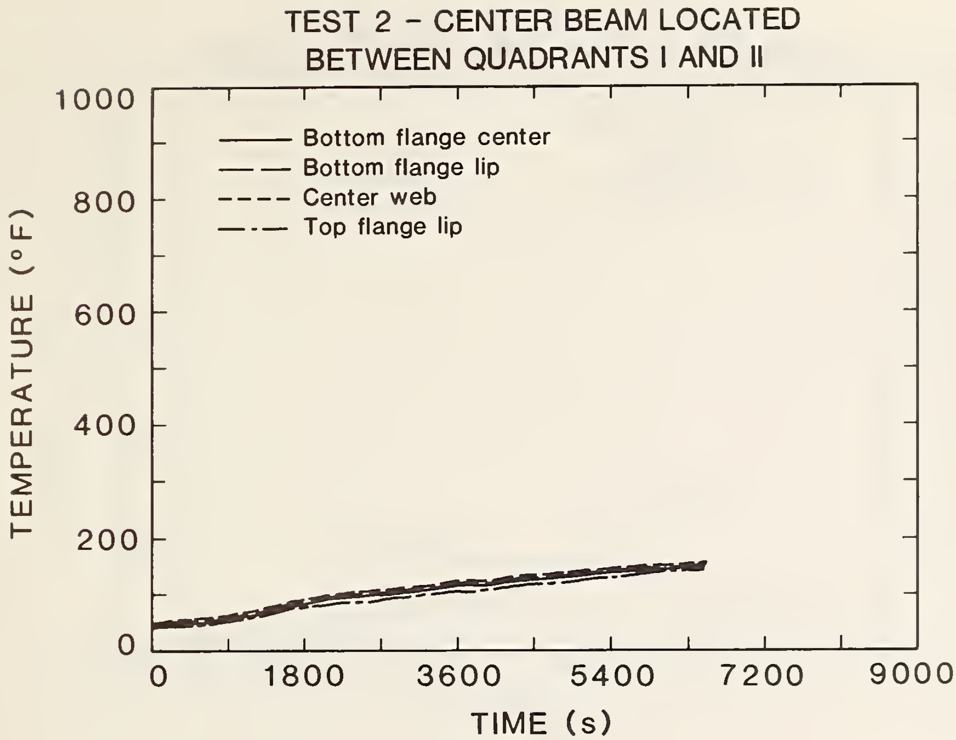


Figure 60. Temperatures for center beam supporting the functional floor, center measurement point between quadrants I and II, test 2

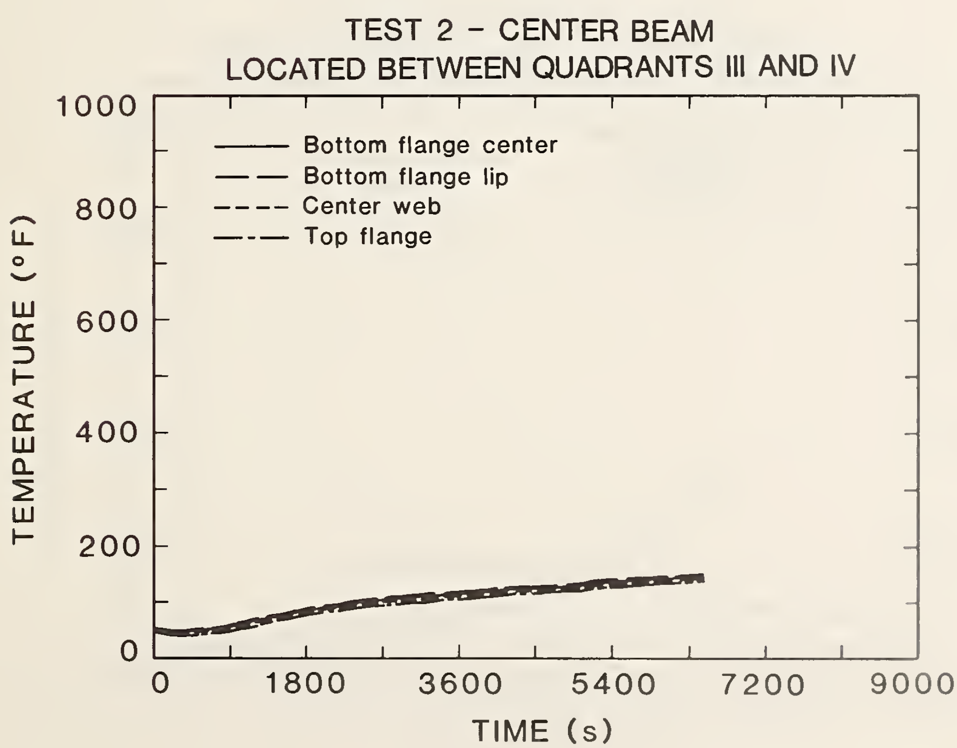


Figure 61. Temperatures for center beam supporting the functional floor, center measurement point between quadrants III and IV, test 2

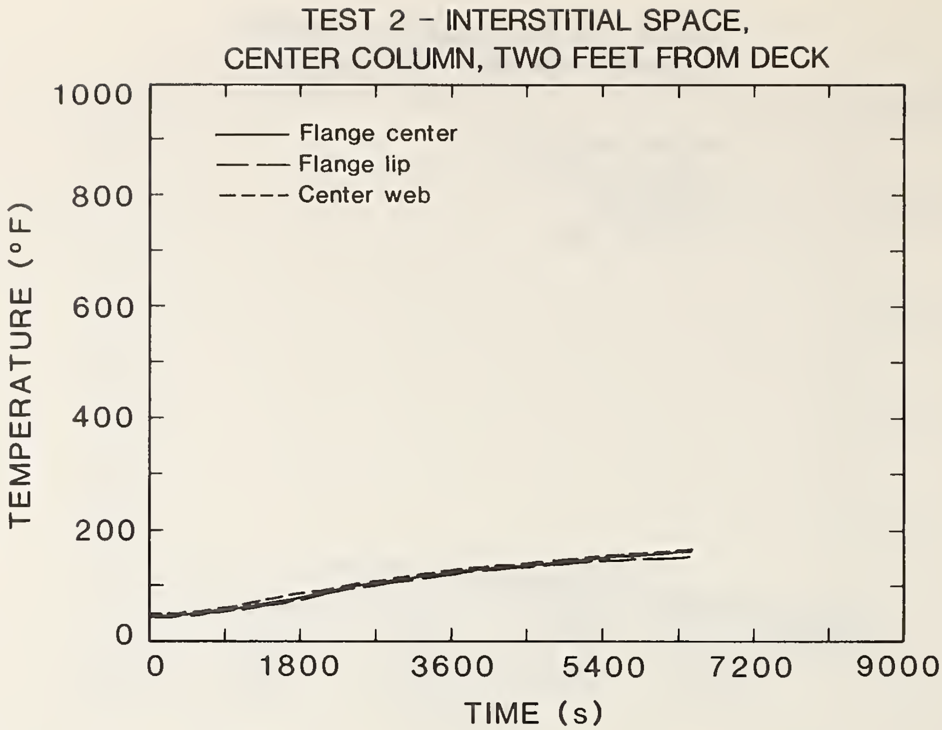


Figure 62. Center column temperatures in interstitial space at measurement point two feet above walk-on deck, test 2

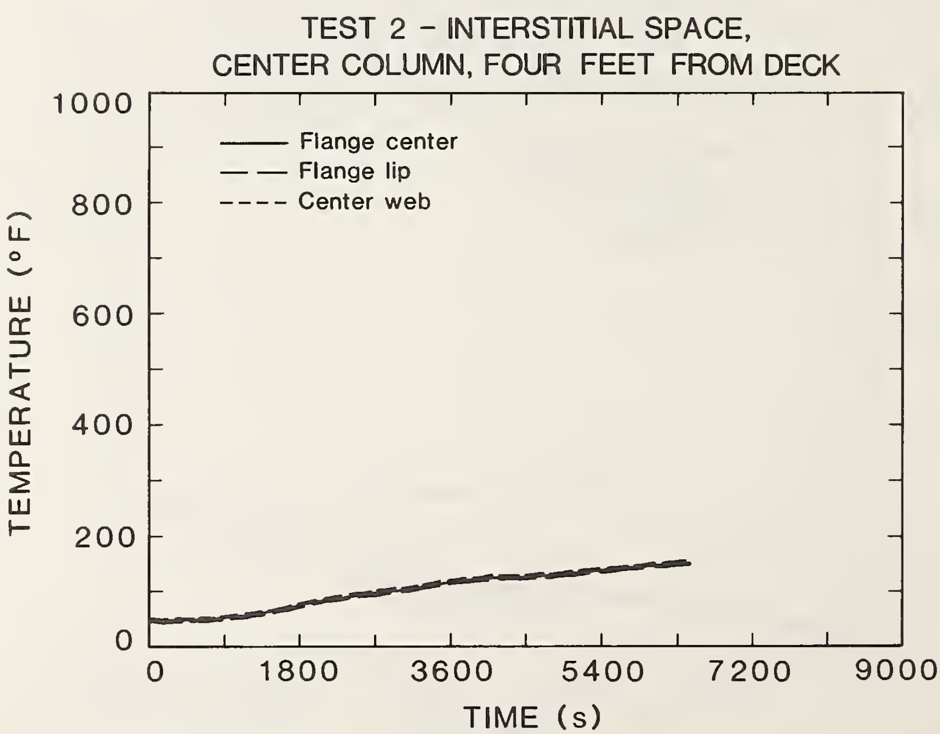


Figure 63. Center column temperatures in interstitial space at measurement point four feet above walk-on deck, test 2

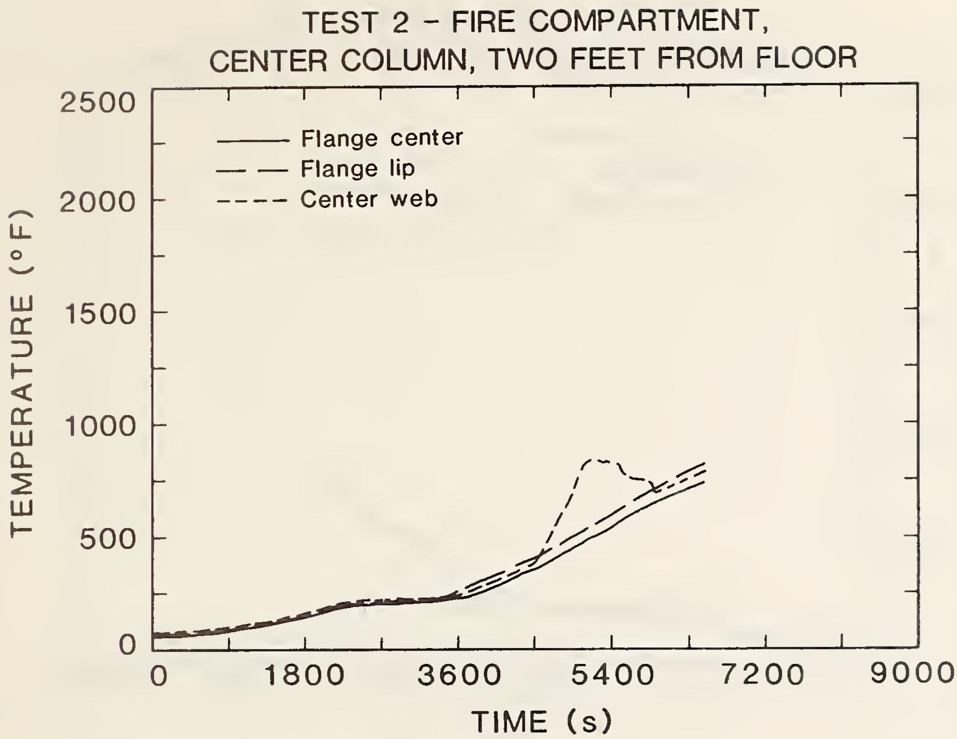


Figure 64. Column temperatures in furnace compartment two feet up from floor, test 2

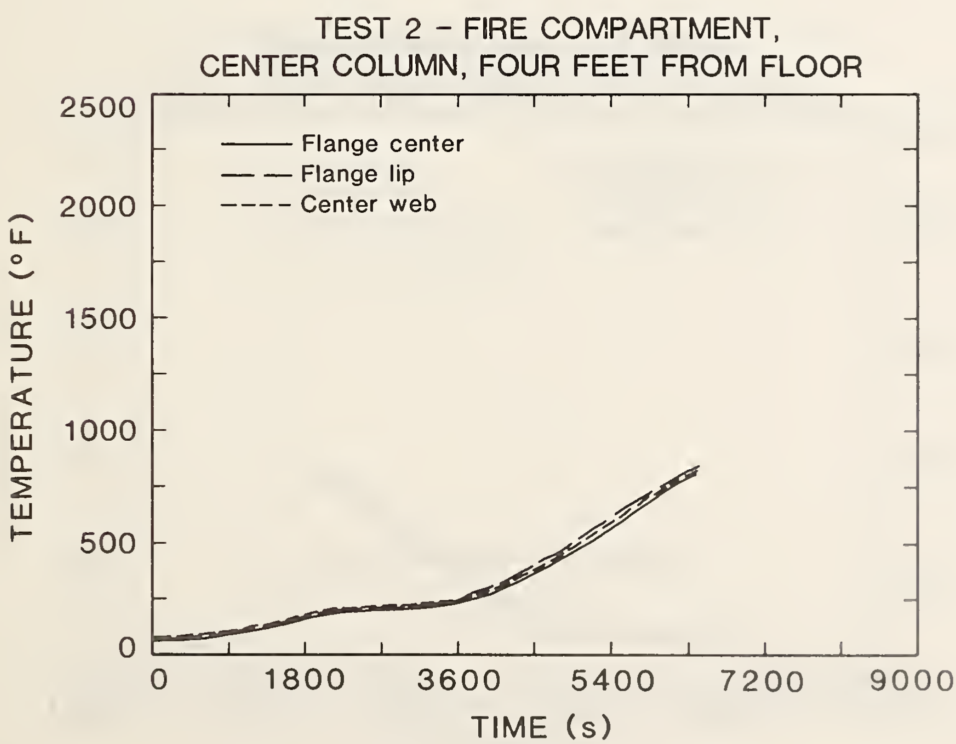


Figure 65. Column temperatures in furnace compartment four feet up from floor, test 2

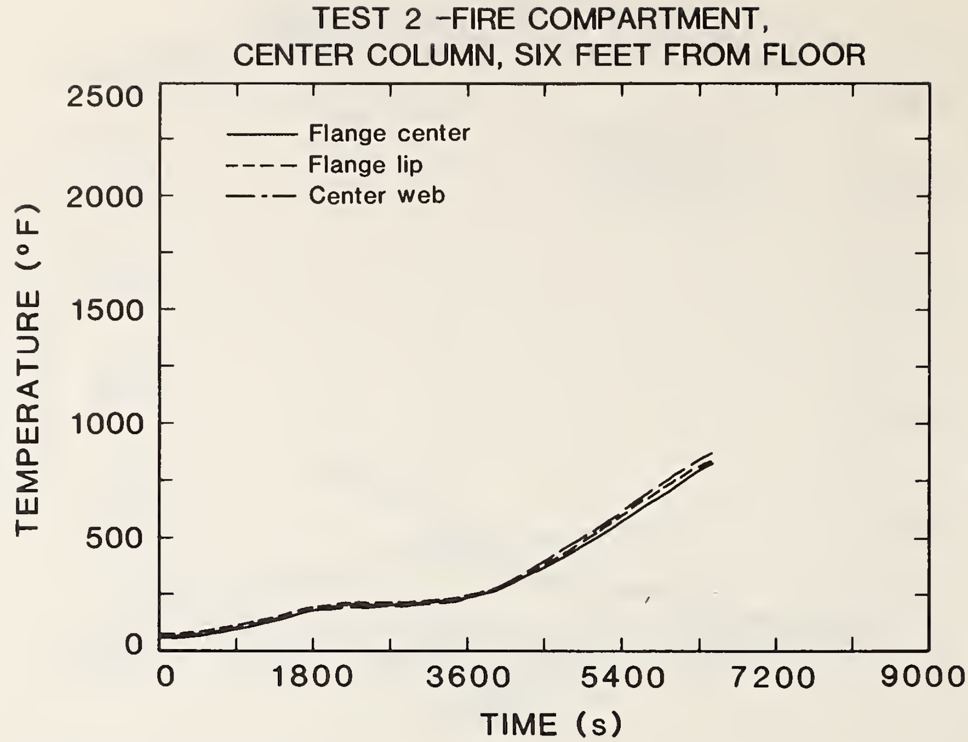


Figure 66. Column temperatures in furnace compartment six feet up from floor, test 2

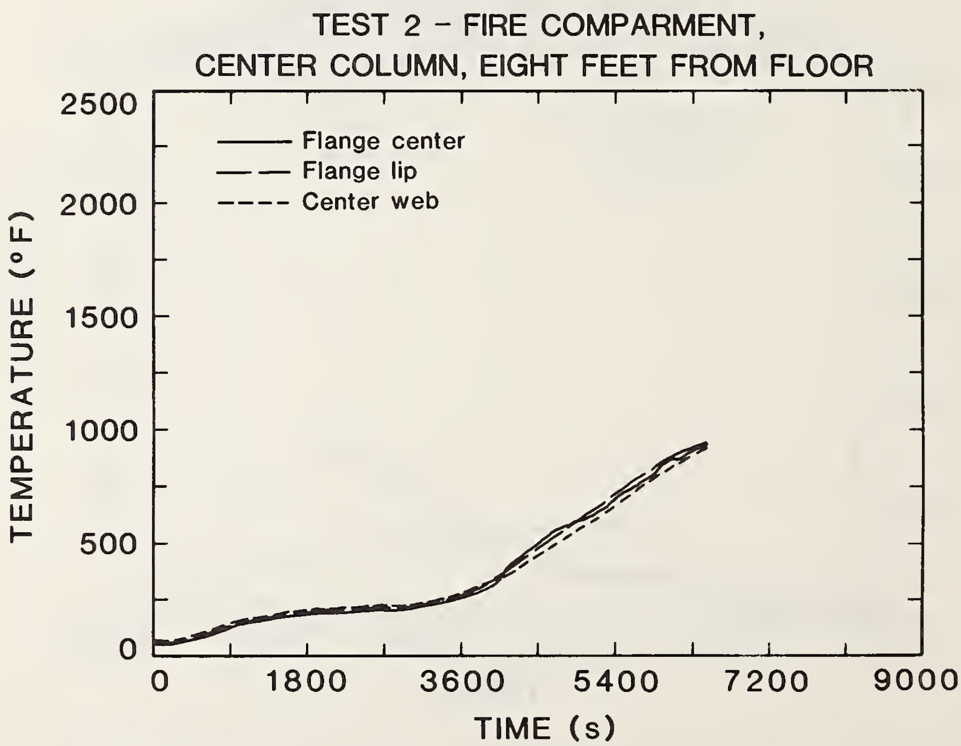


Figure 67. Column temperatures in furnace compartment eight feet up from floor, test 2

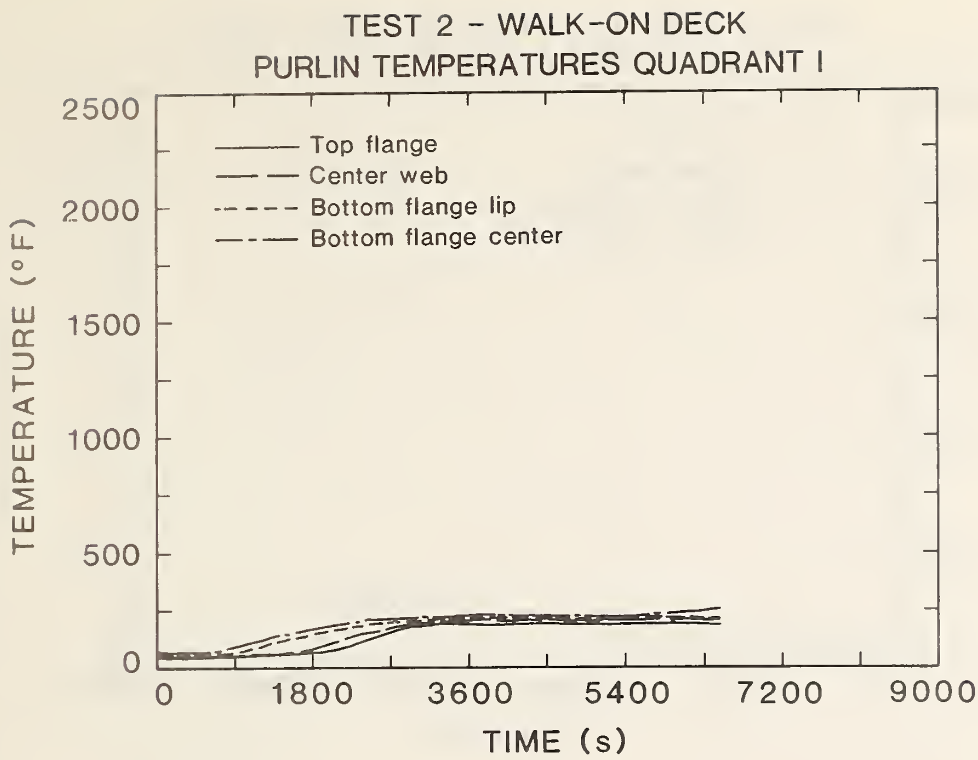


Figure 68. Walk-on deck purlin temperatures quadrant I, test 2

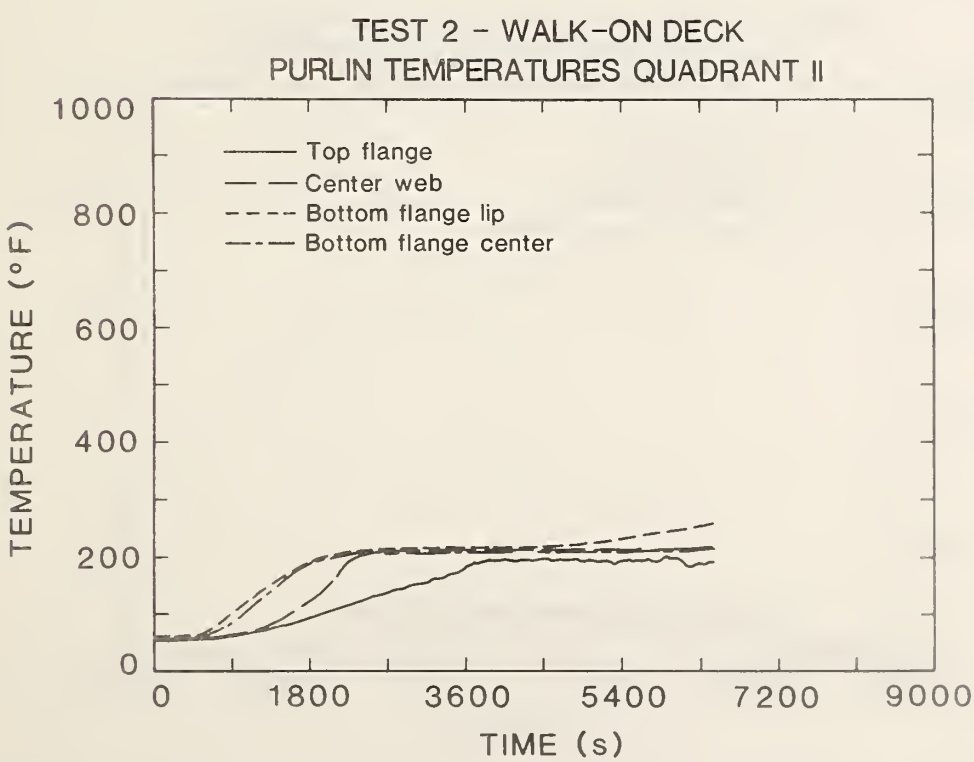


Figure 69. Walk-on deck purlin temperatures quadrant II, test 2

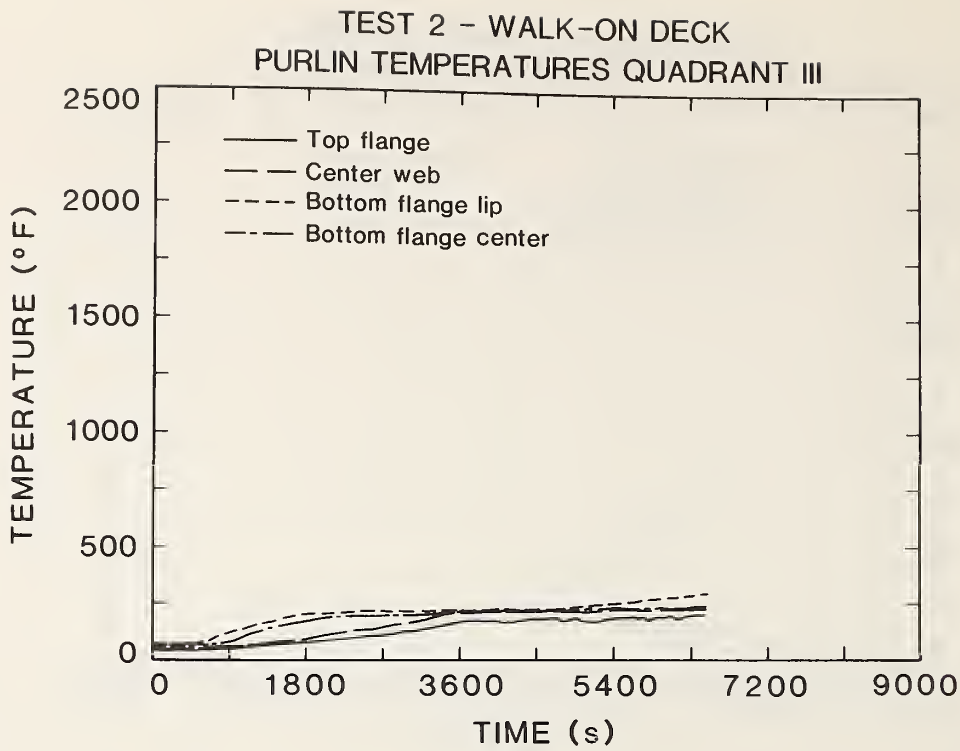


Figure 70. Walk-on deck purlin temperatures quadrant III, test 2

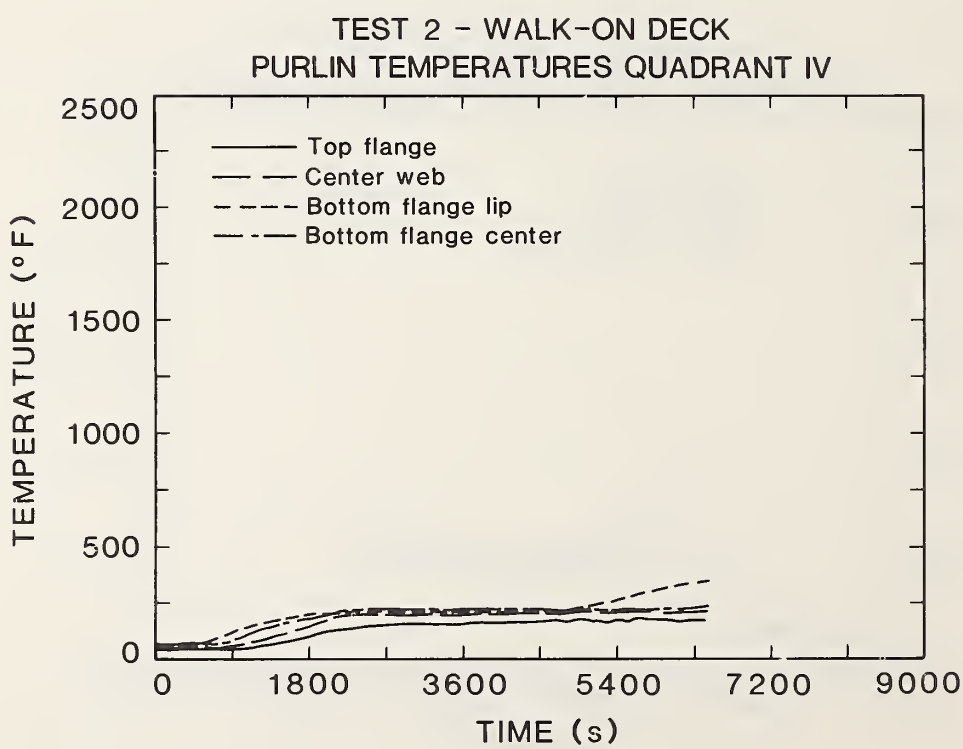


Figure 71. Walk-on deck purlin temperatures quadrant IV, test 2

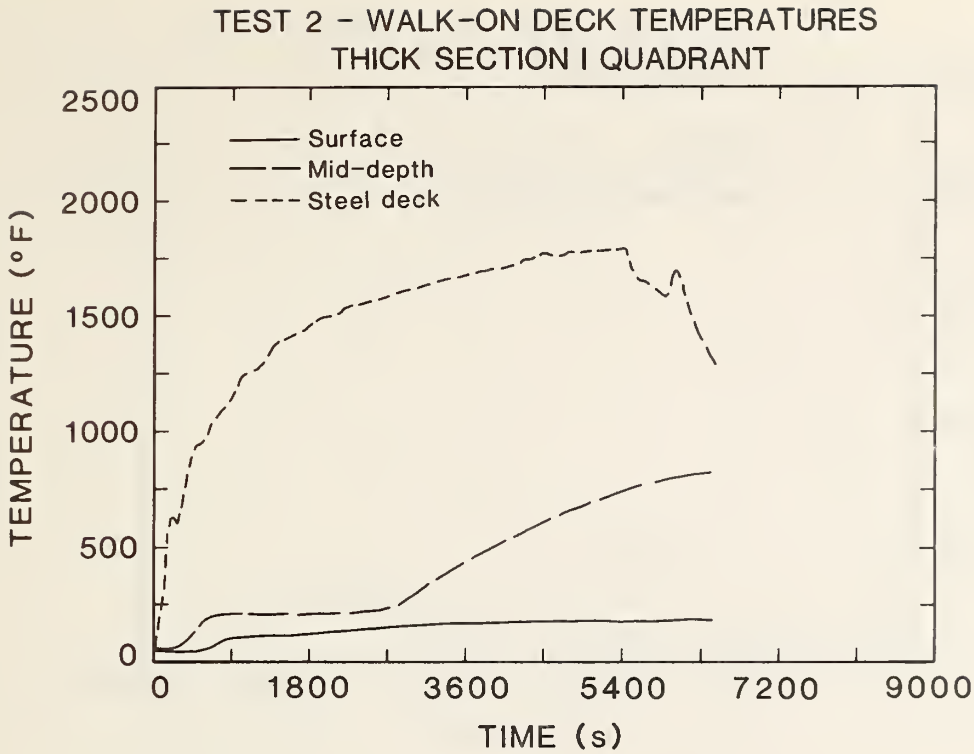


Figure 72. Walk-on deck purlin temperatures thick section quadrant I, test 2

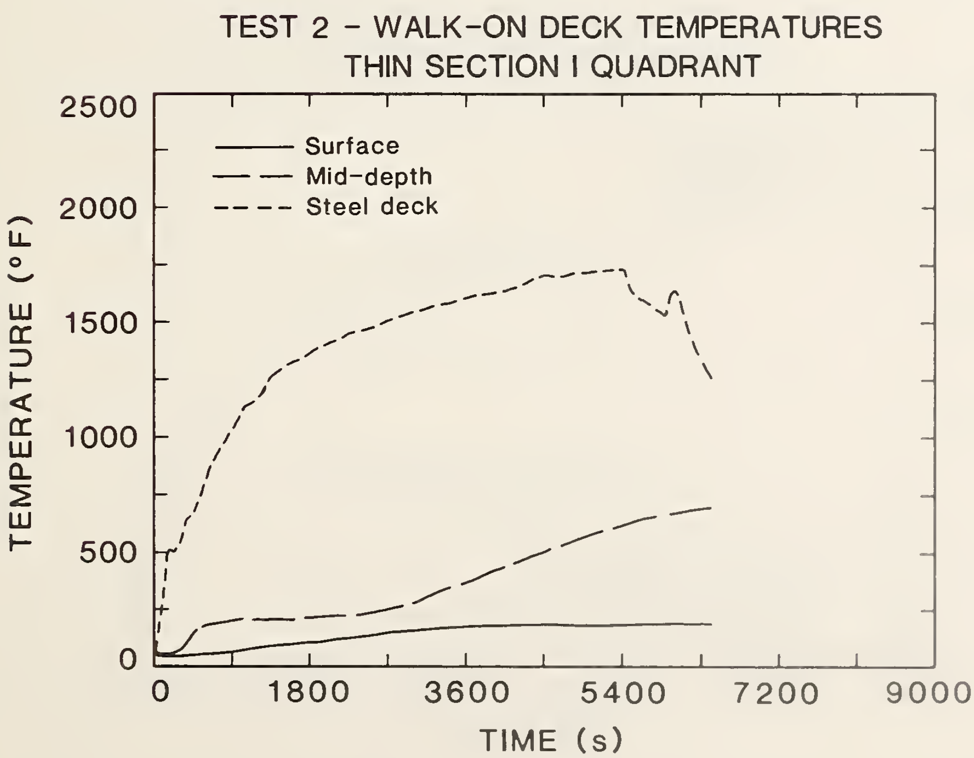


Figure 73. Walk-on deck temperatures thin section quadrant I, test 2

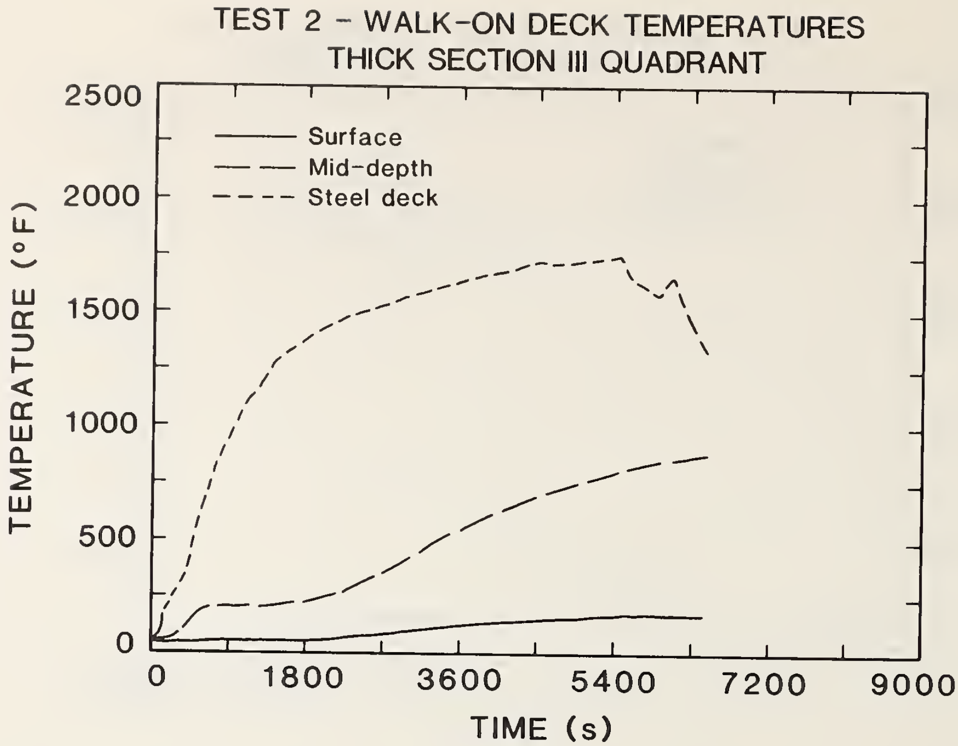


Figure 74. Walk-on deck temperatures thick section quadrant III, test 2

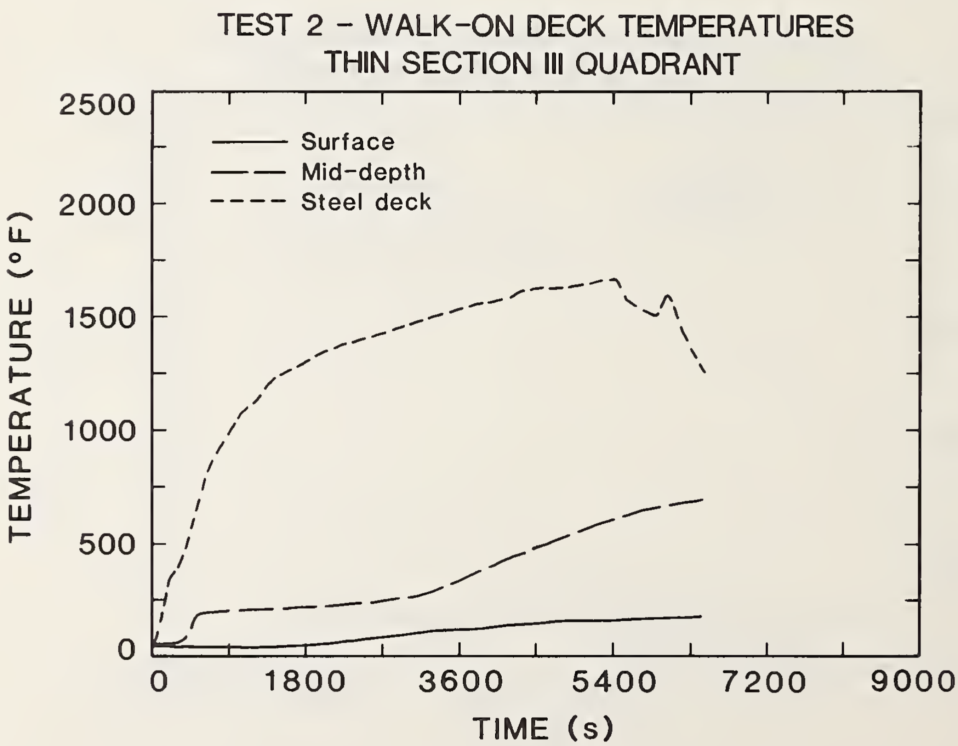


Figure 75. Walk-on deck temperatures thin section quadrant III, test 2

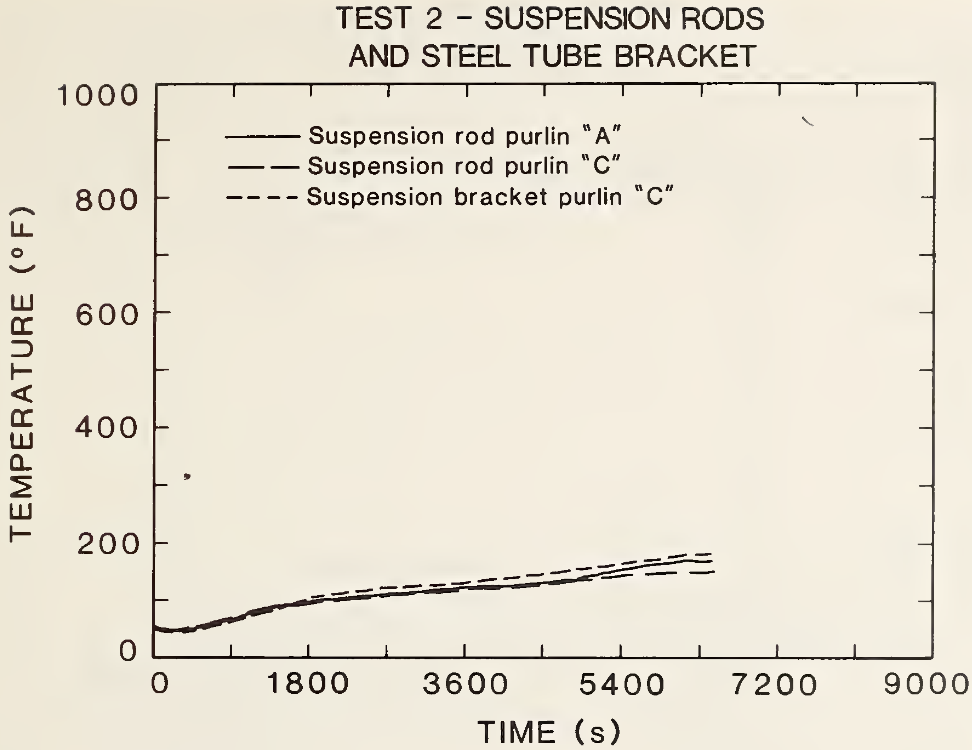


Figure 76. Temperatures for suspension rods and steel tube bracket, test 2

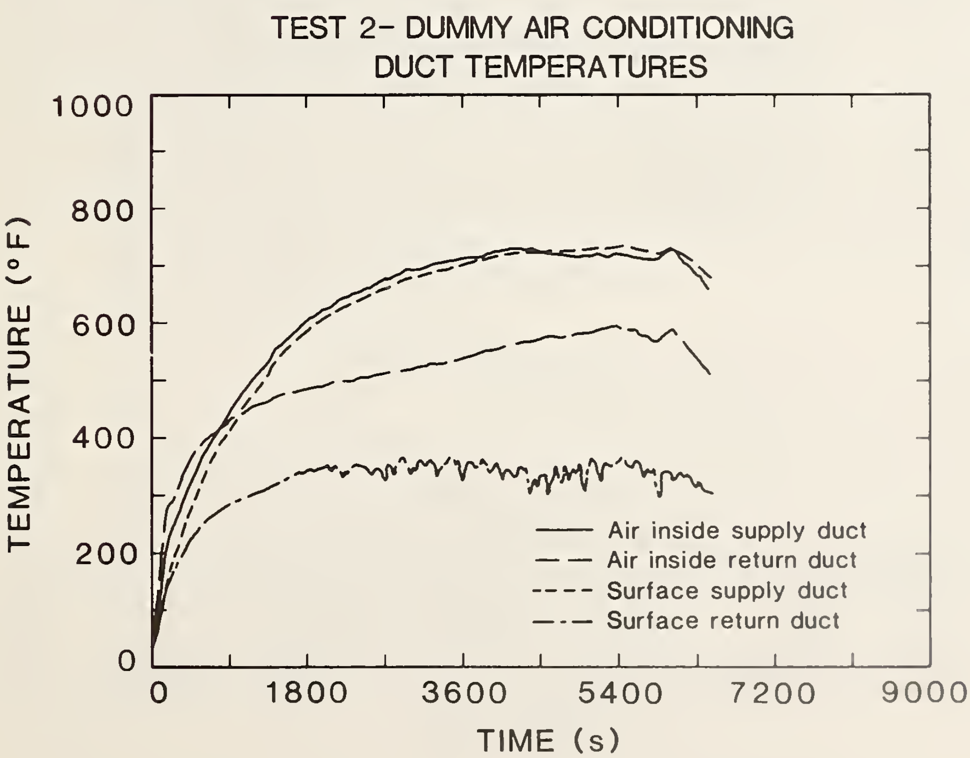


Figure 77. Dummy air conditioning duct temperatures, test 2

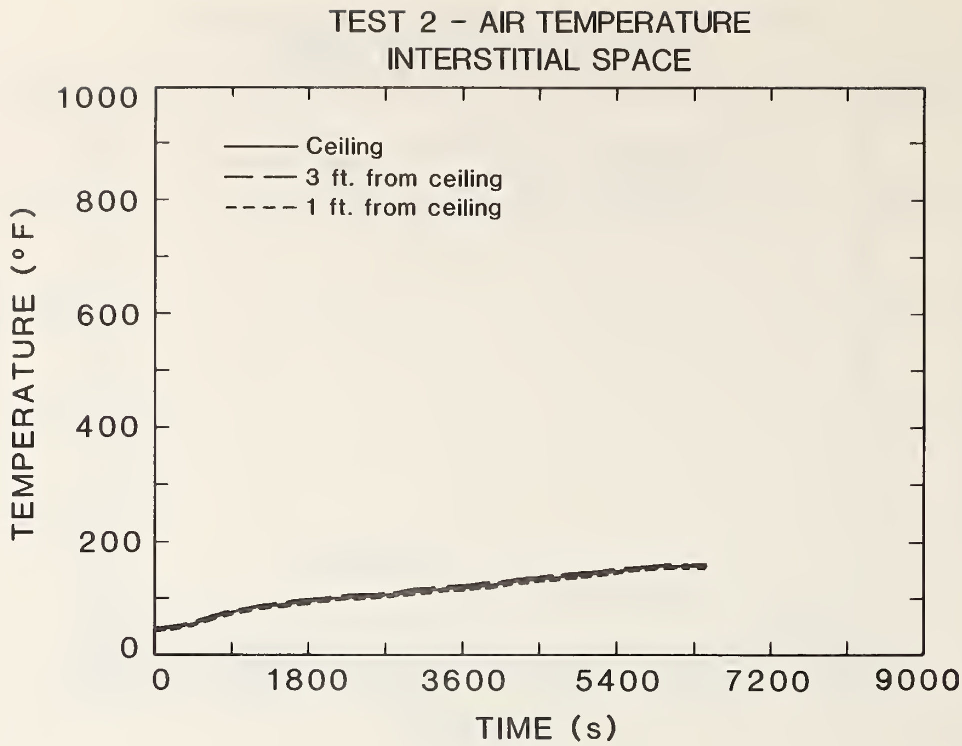


Figure 78. Interstitial space air temperatures, test 2

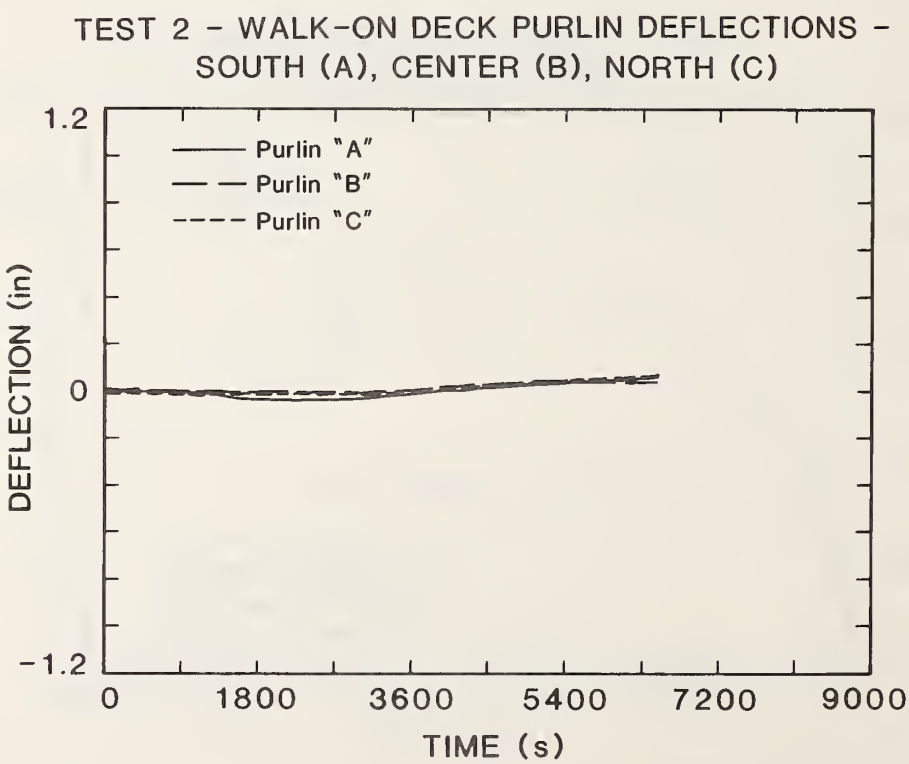


Figure 79. Walk-on deck purlin deflections, test 2

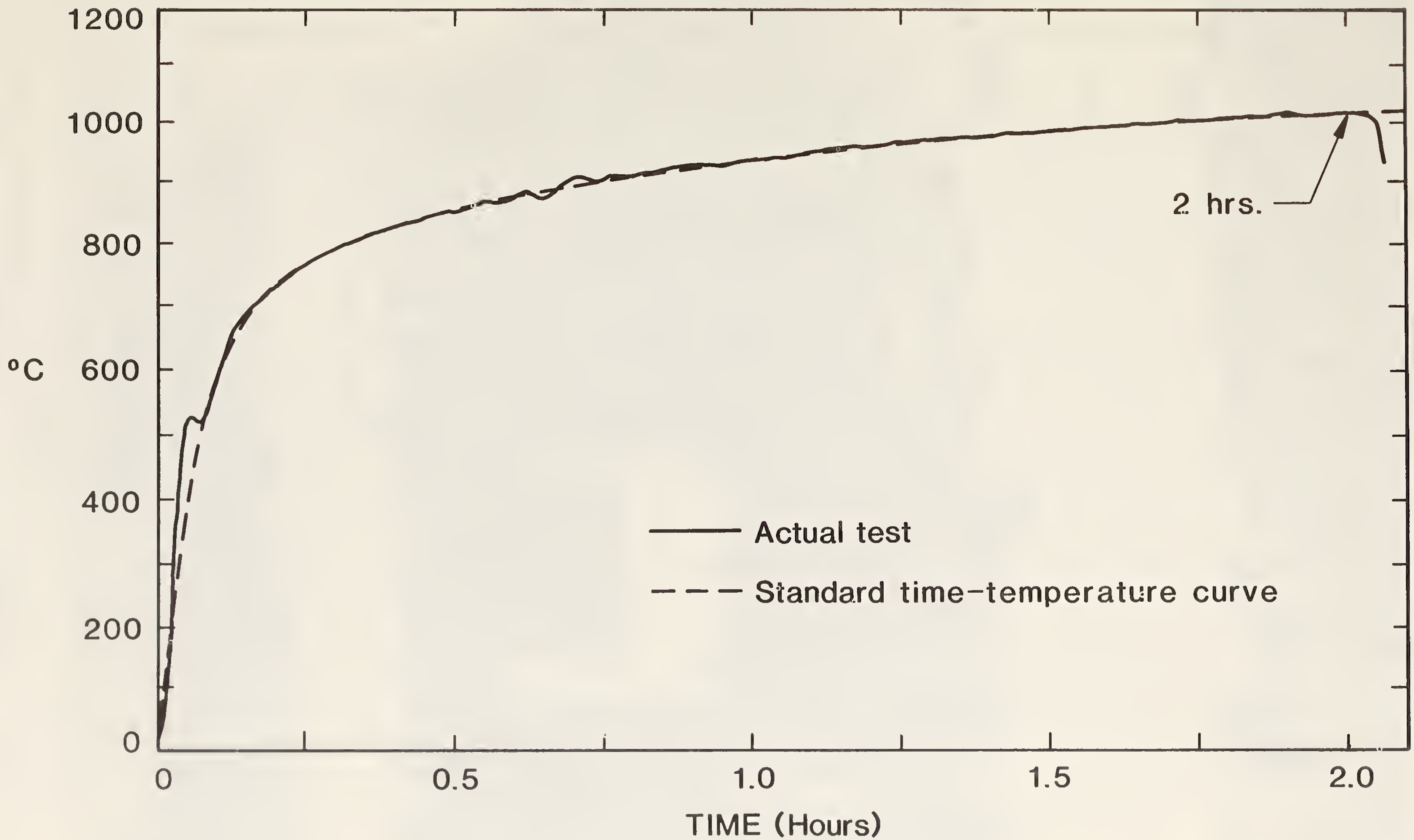


Figure 80. Chart record of average furnace temperature, test 2A

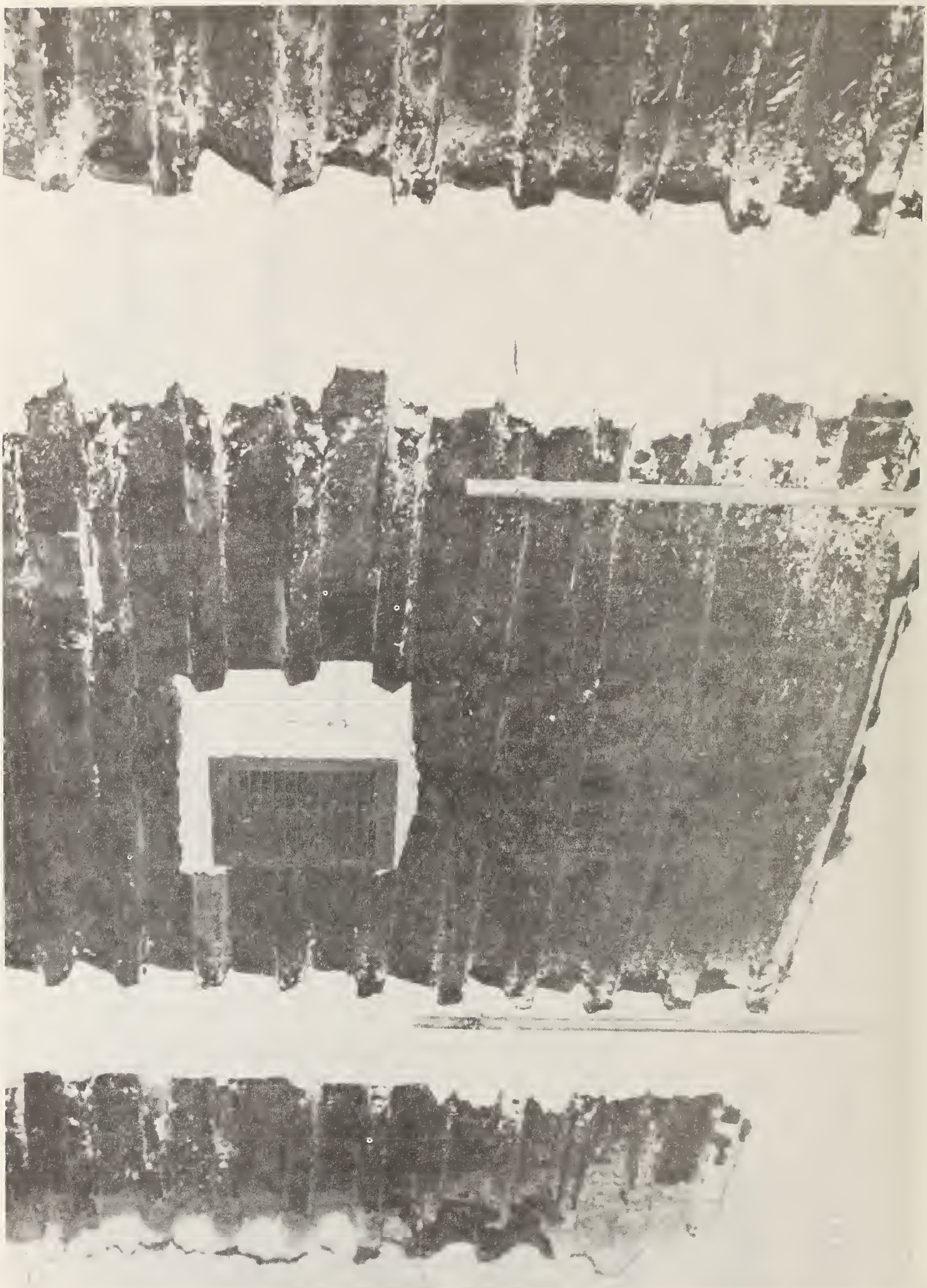


Figure 81. Photograph showing bottom of walk-on deck at end of test 2A

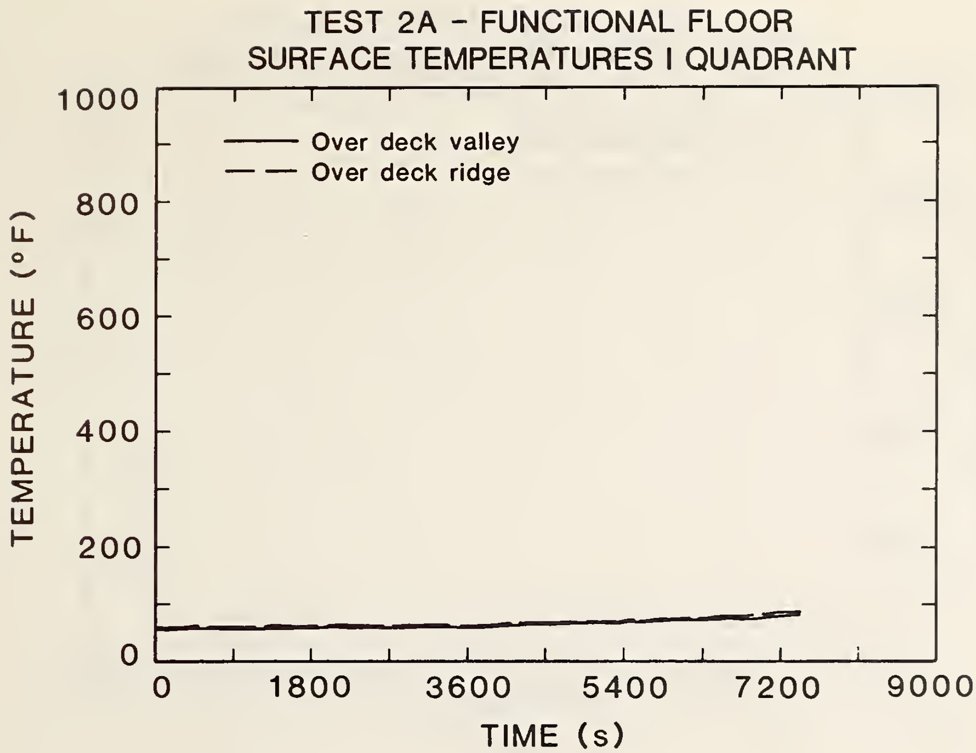


Figure 82. Functional floor surface temperatures quadrant I, test 2A

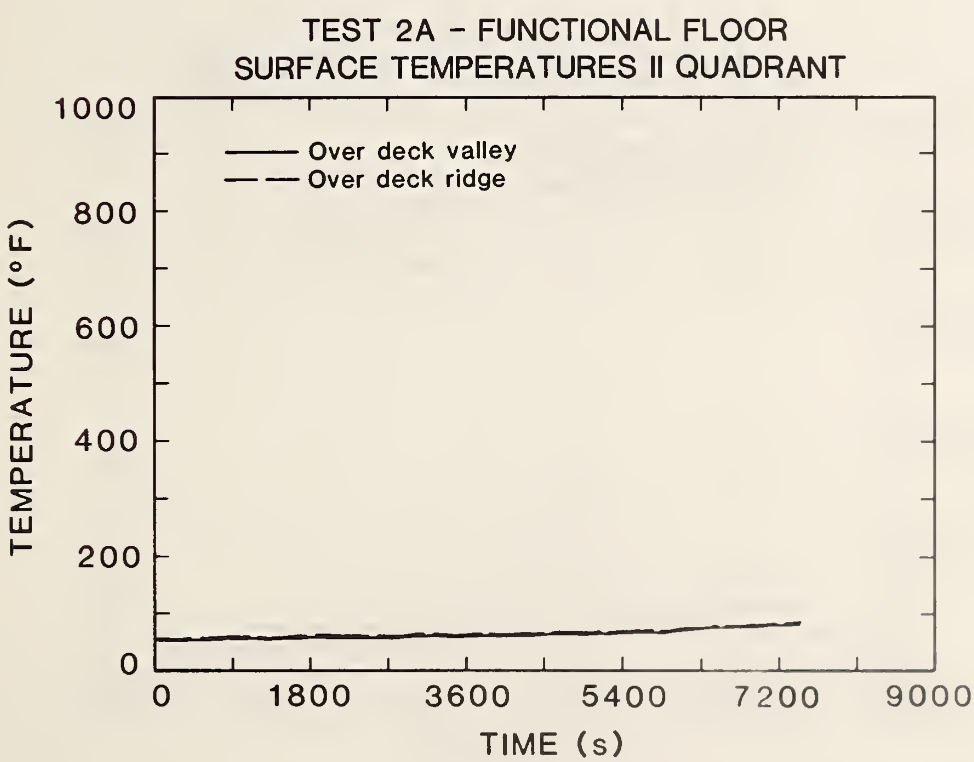


Figure 83. Functional floor surface temperatures quadrant II, test 2A

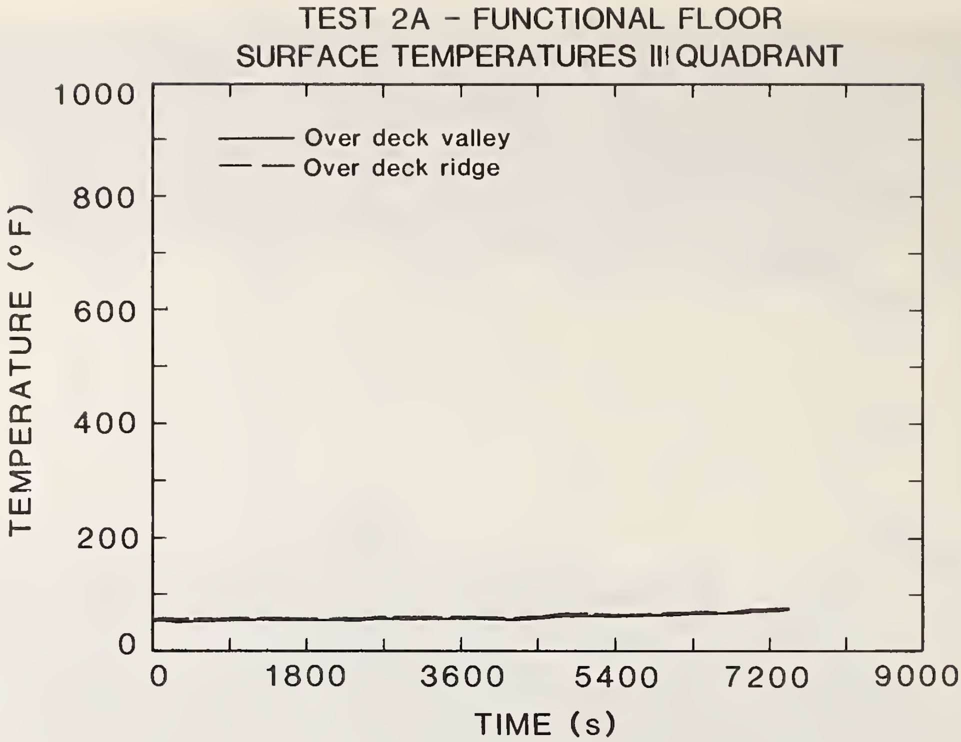


Figure 84. Functional floor surface temperatures quadrant III, test 2A

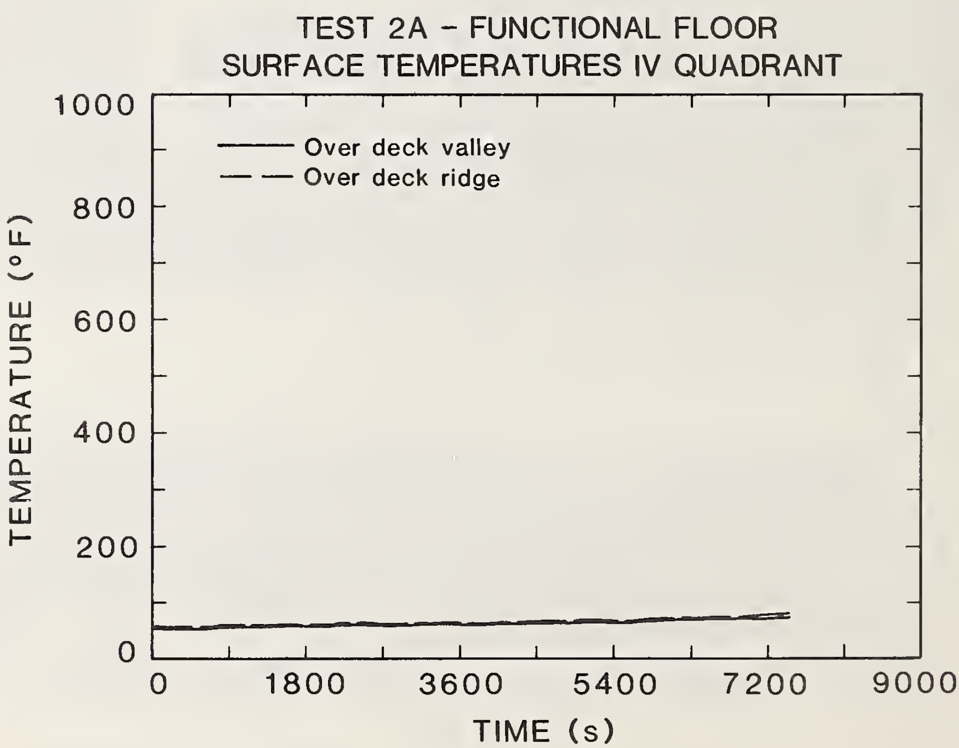


Figure 85. Functional floor surface temperatures quadrant IV, test 2A

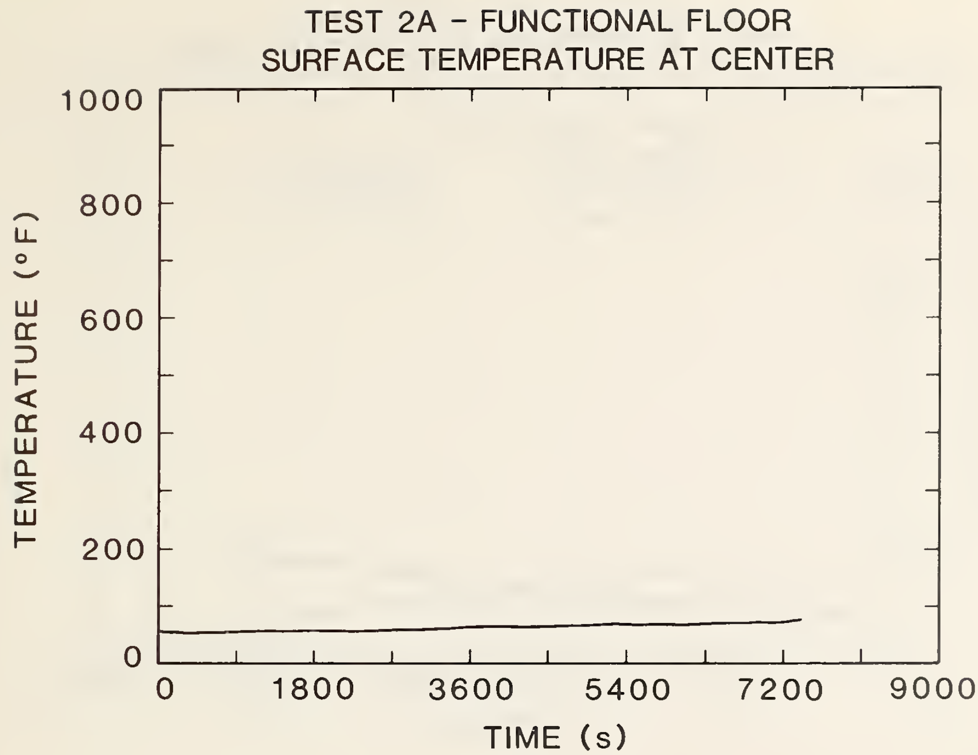


Figure 86. Functional floor surface temperature center of test bay, test 2A

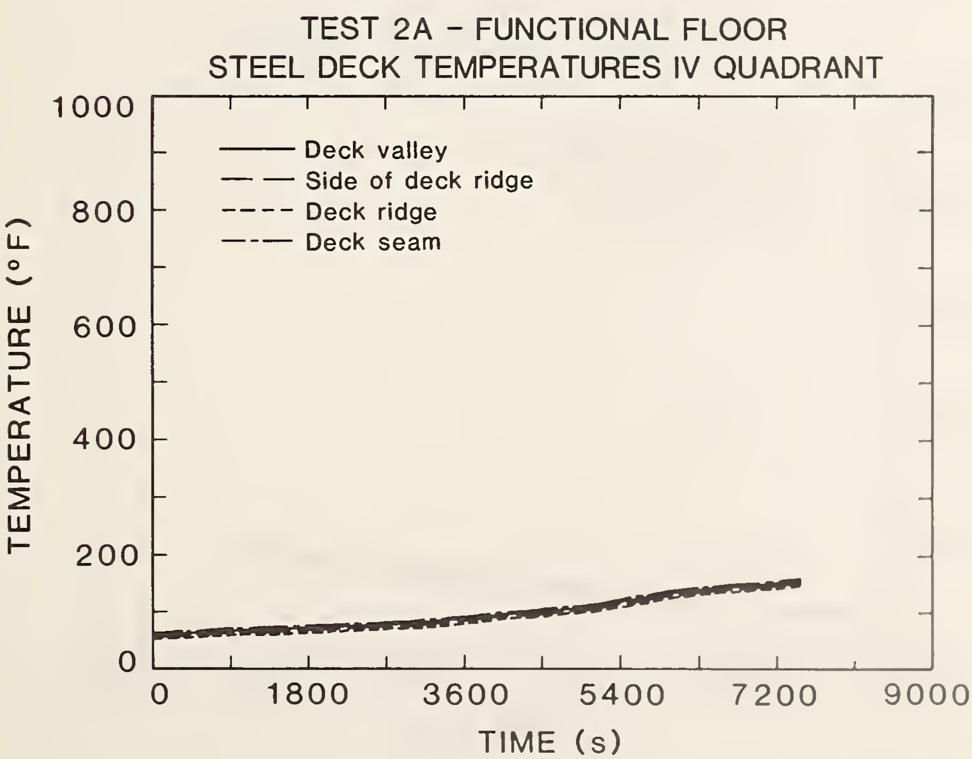


Figure 87. Functional floor steel deck temperatures quadrant IV, test 2A

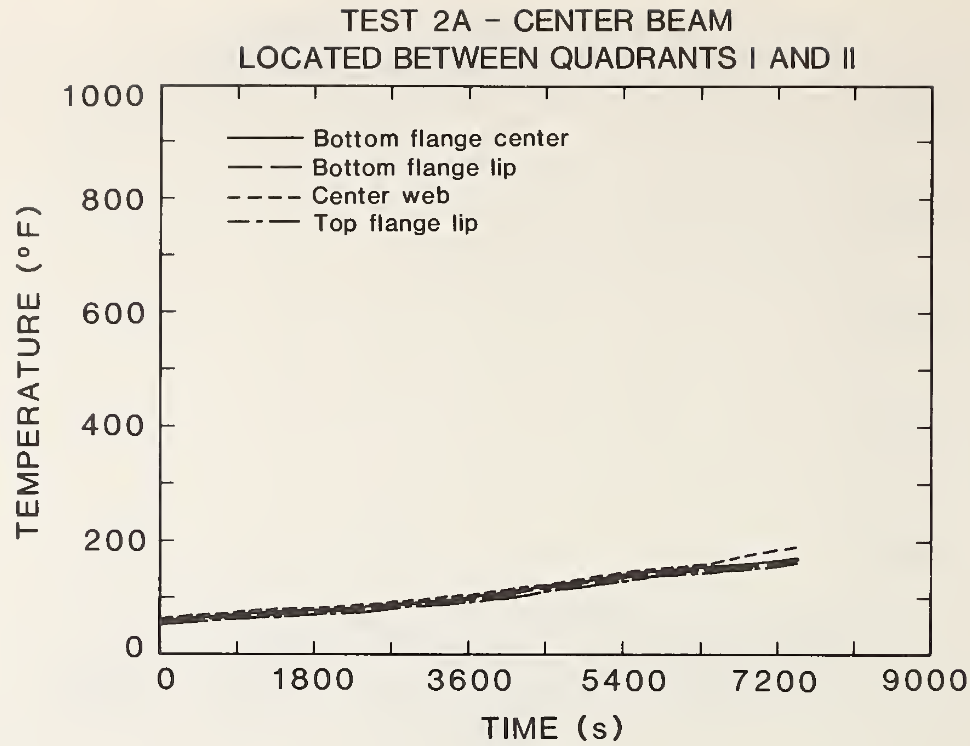


Figure 88. Temperatures for center beam supporting the functional floor, center measurement point between quadrants I and II, test 2A

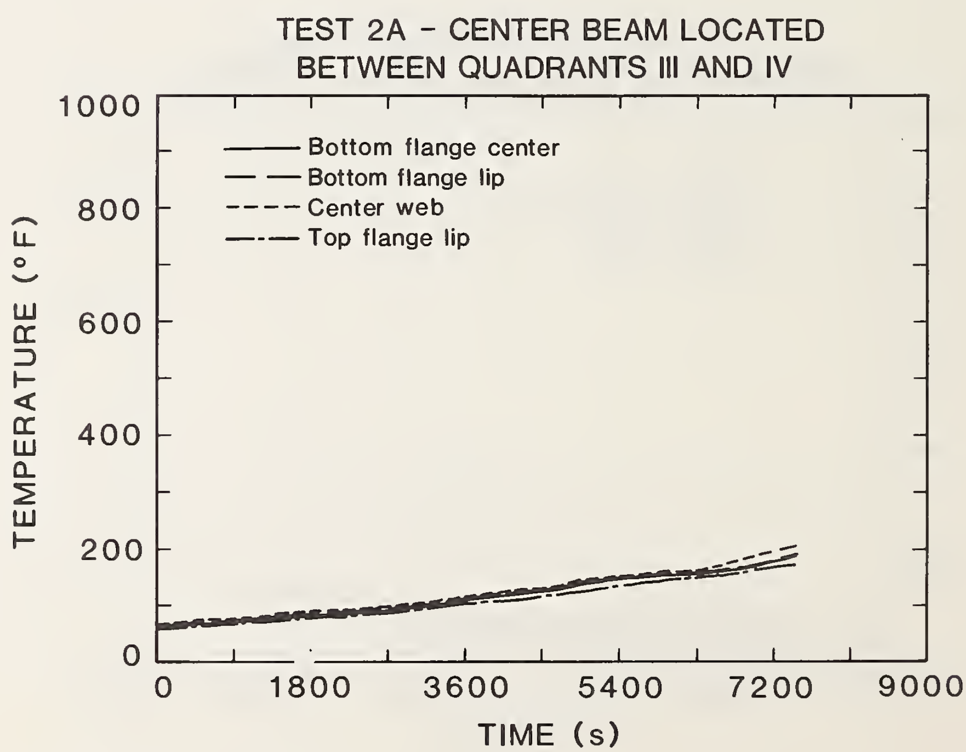


Figure 89. Temperatures for center beam supporting the functional floor, center measurement point between quadrants III and IV, test 2A

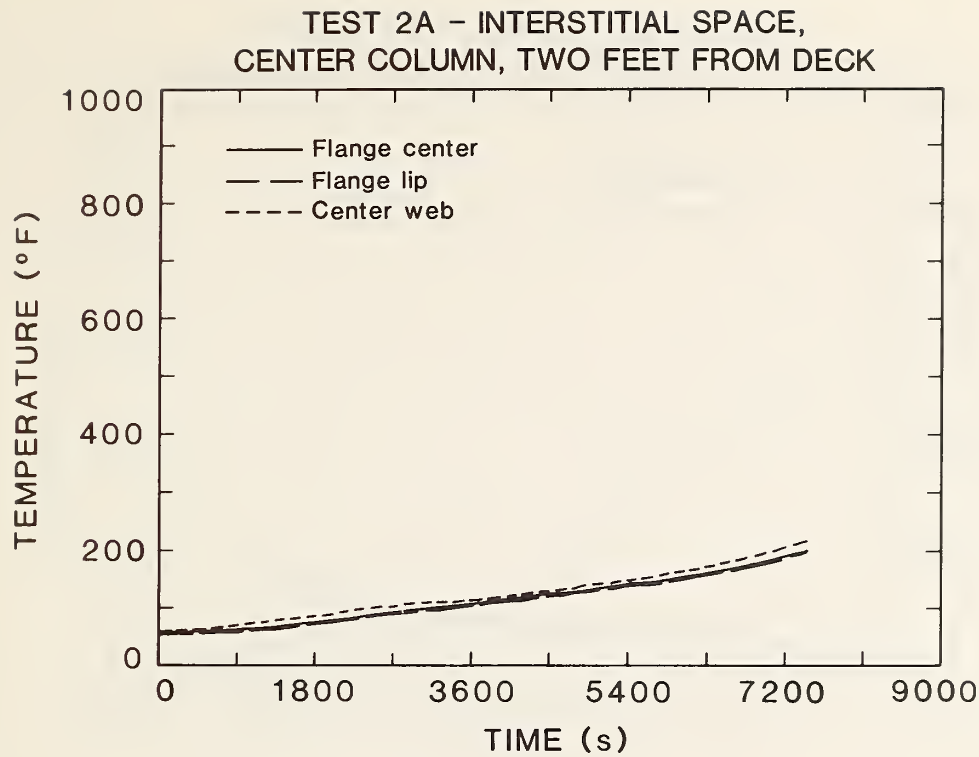


Figure 90. Center column temperatures in interstitial space at measurement point two feet above walk-on deck, test 2A

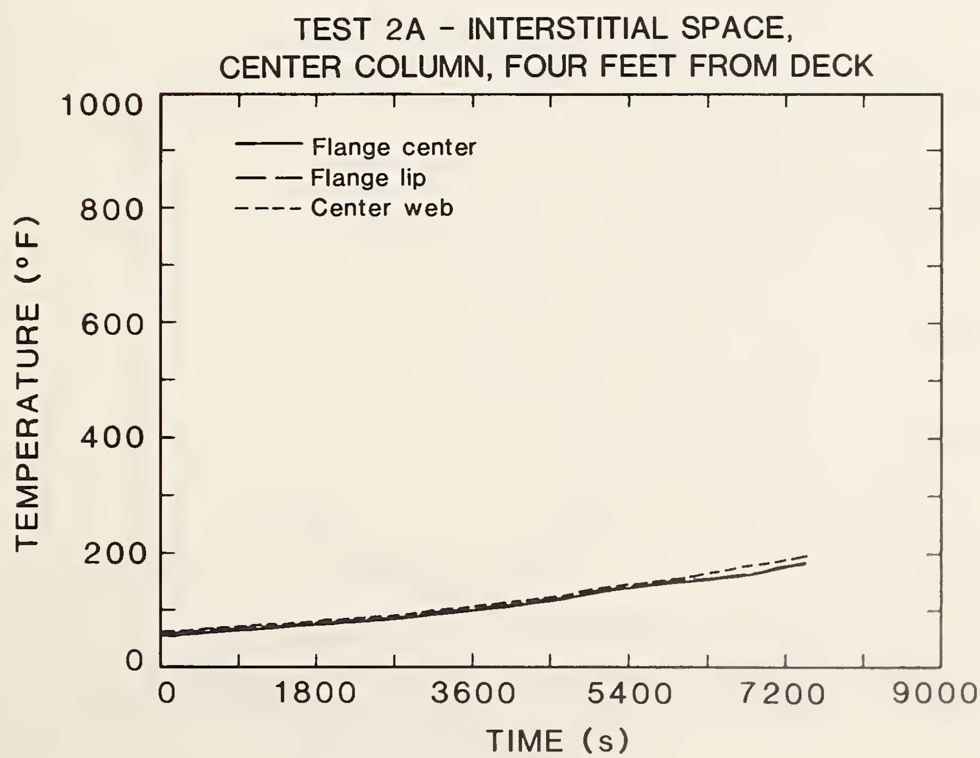


Figure 91. Center column temperatures in interstitial space at measurement point four feet above walk-on deck, test 2A

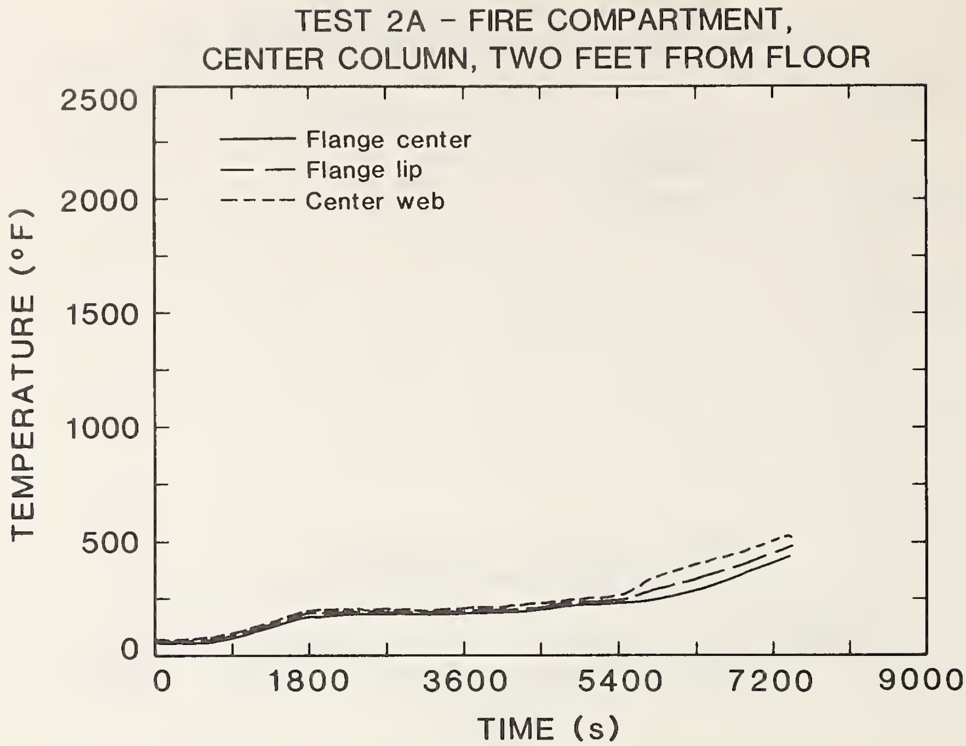


Figure 92. Column temperatures in furnace compartment two feet up from floor, test 2A

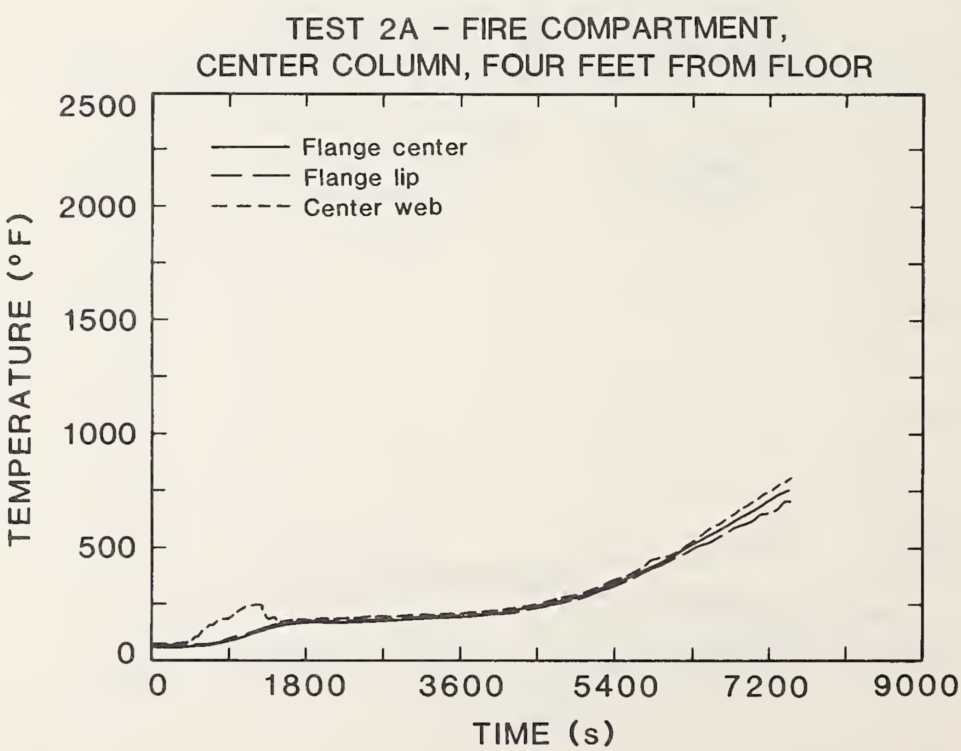


Figure 93. Column temperatures in furnace compartment four feet up from floor, test 2A

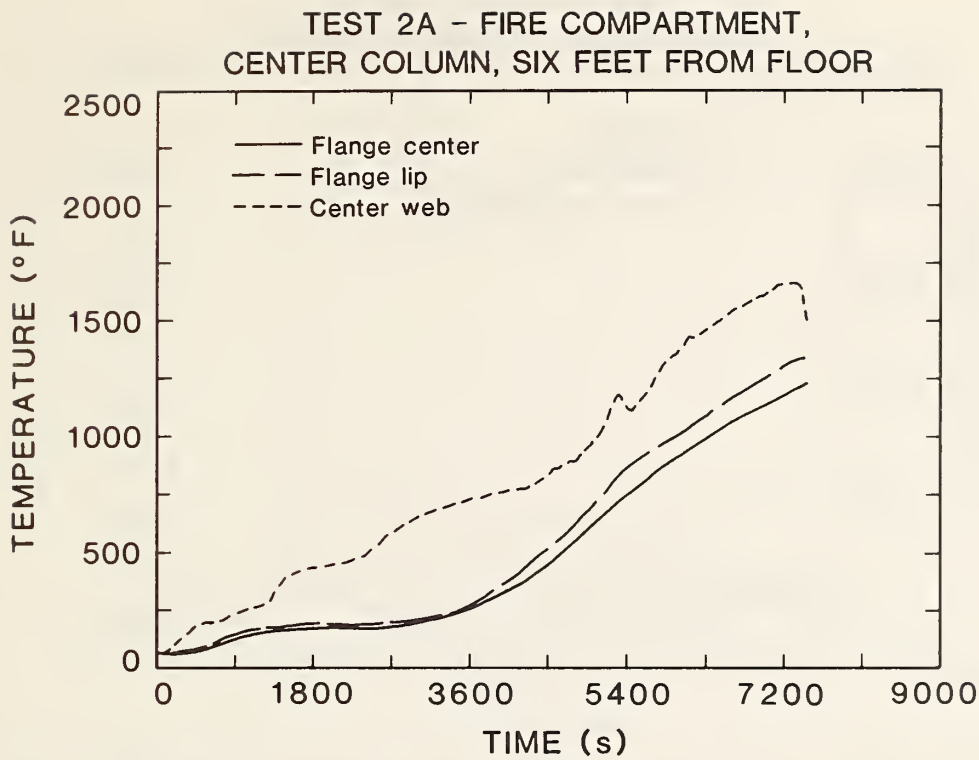


Figure 94. Column temperatures in furnace compartment six feet up from floor, test 2A

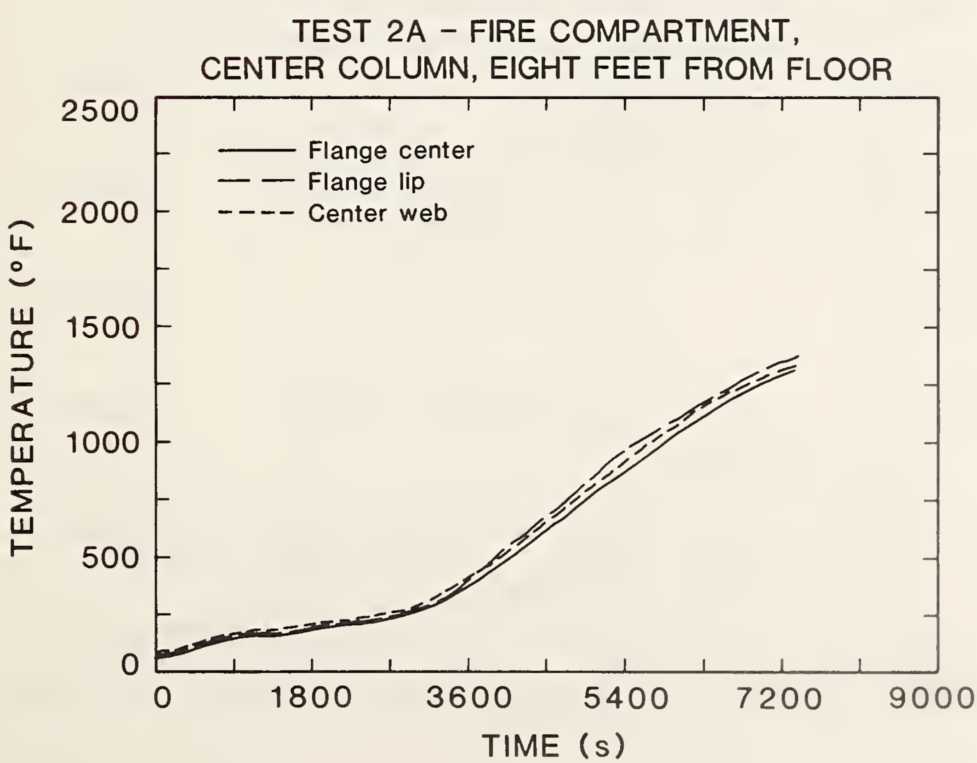


Figure 95. Column temperatures in furnace compartment eight feet up from floor, test 2A

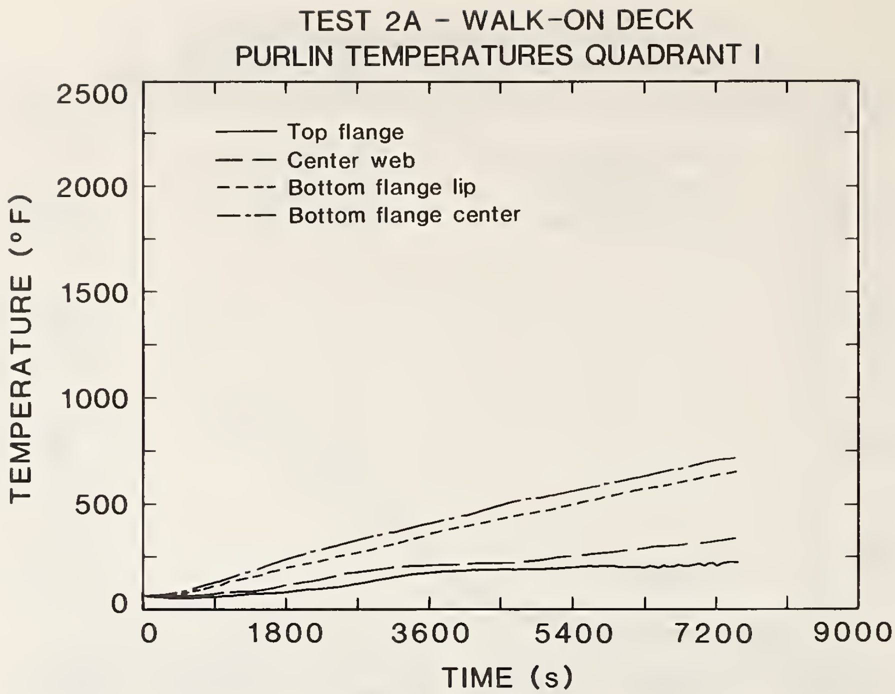


Figure 96. Walk-on deck purlin temperatures quadrant I, test 2A

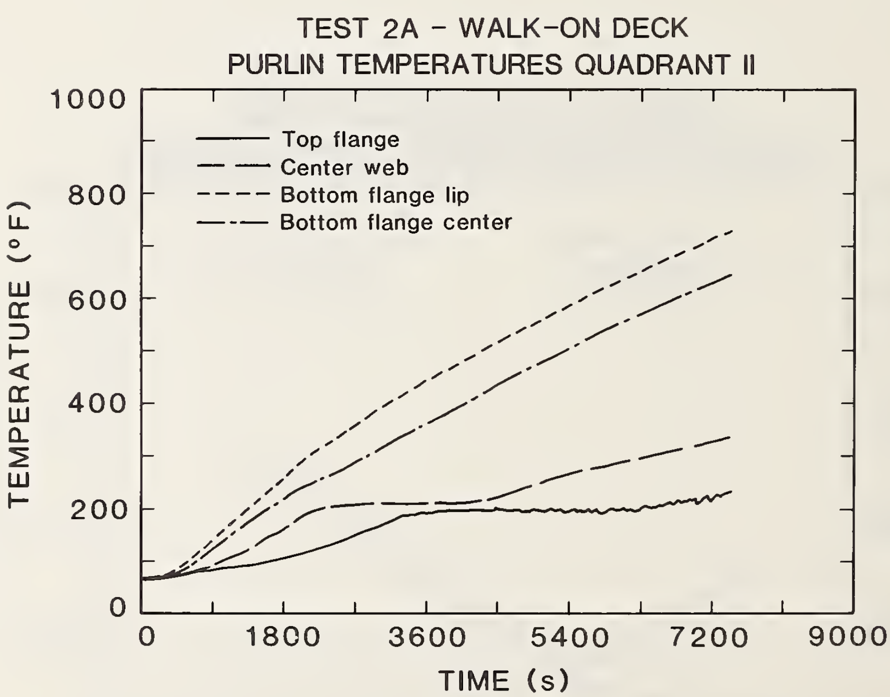


Figure 97. Walk-on deck purlin temperatures quadrant II, test 2A

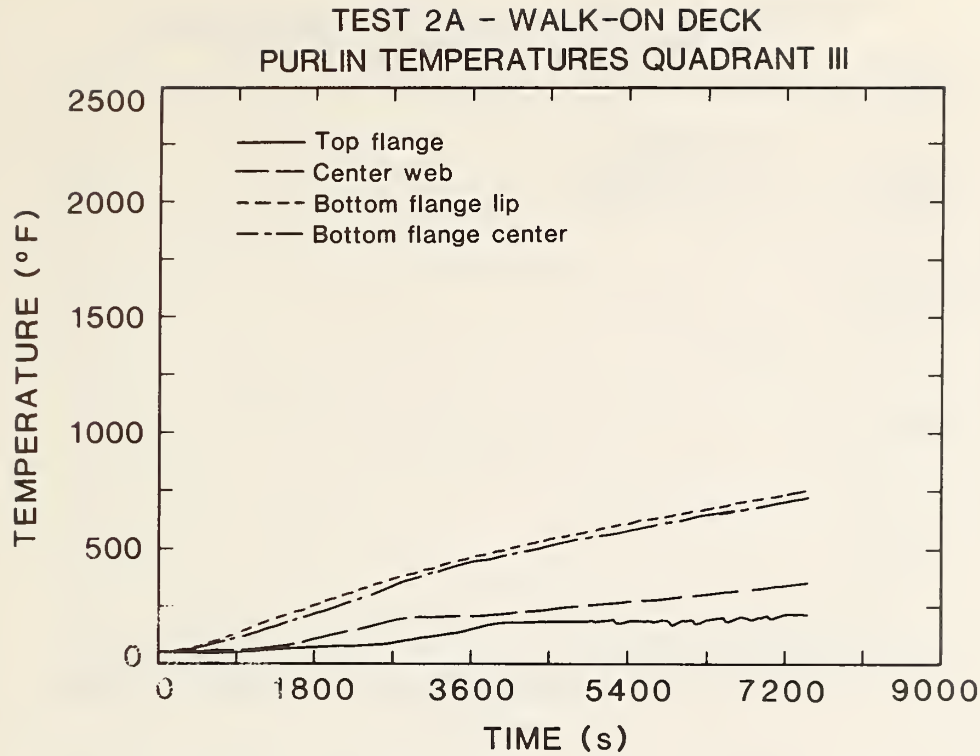


Figure 98. Walk-on deck purlin temperatures quadrant III, test 2A

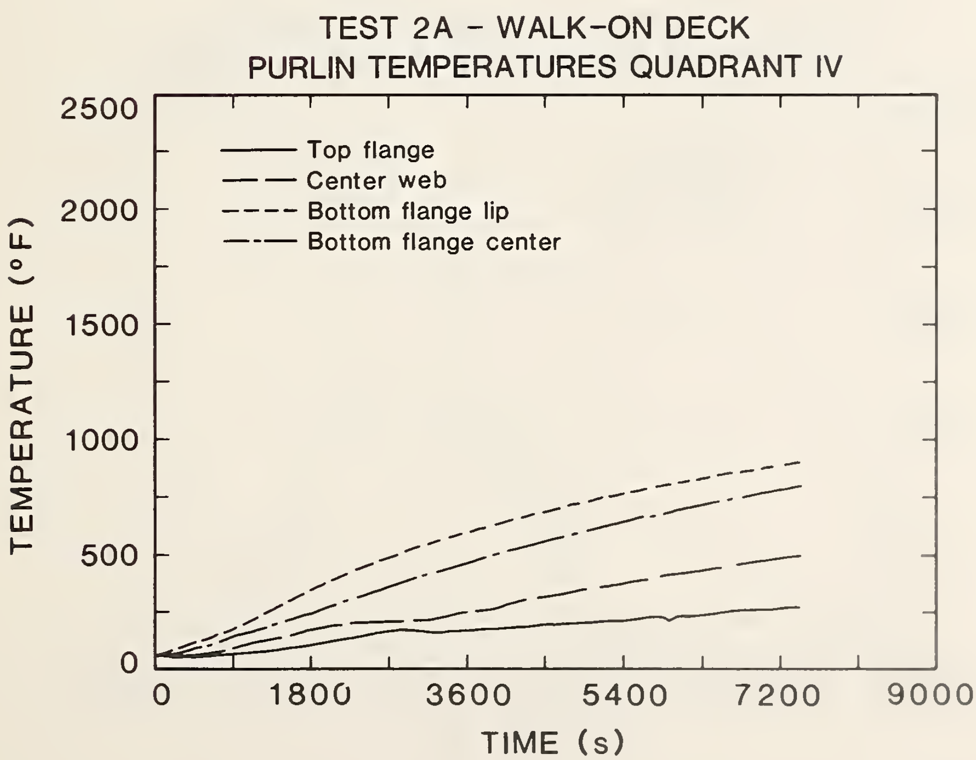


Figure 99. Walk-on deck purlin temperatures quadrant IV, test 2A

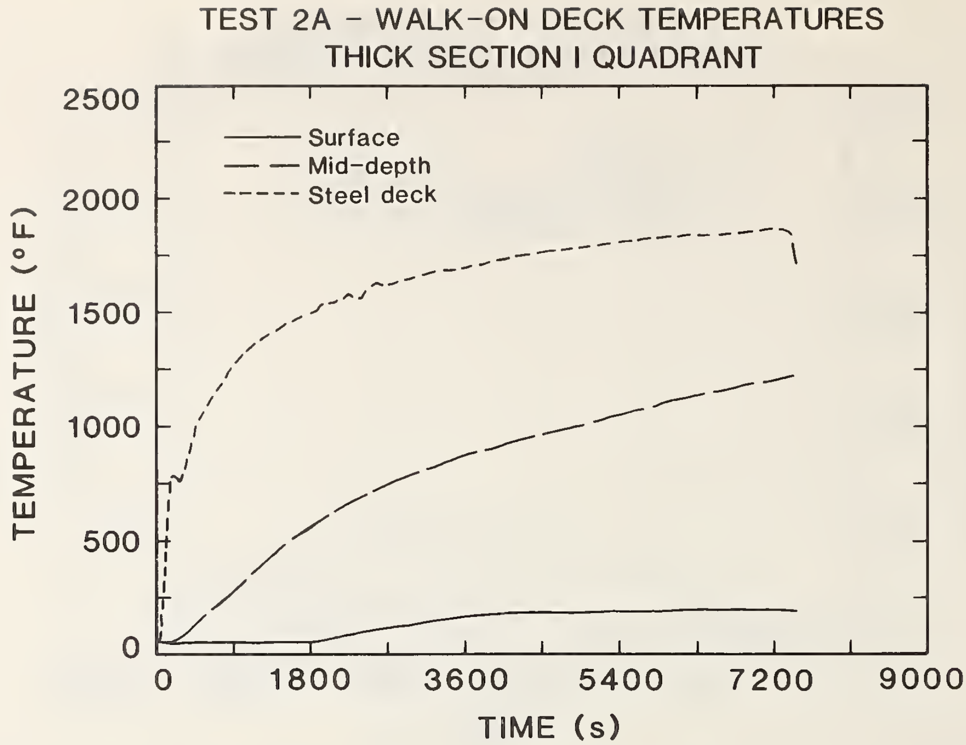


Figure 100. Walk-on deck temperatures thick section quadrant I, test 2A

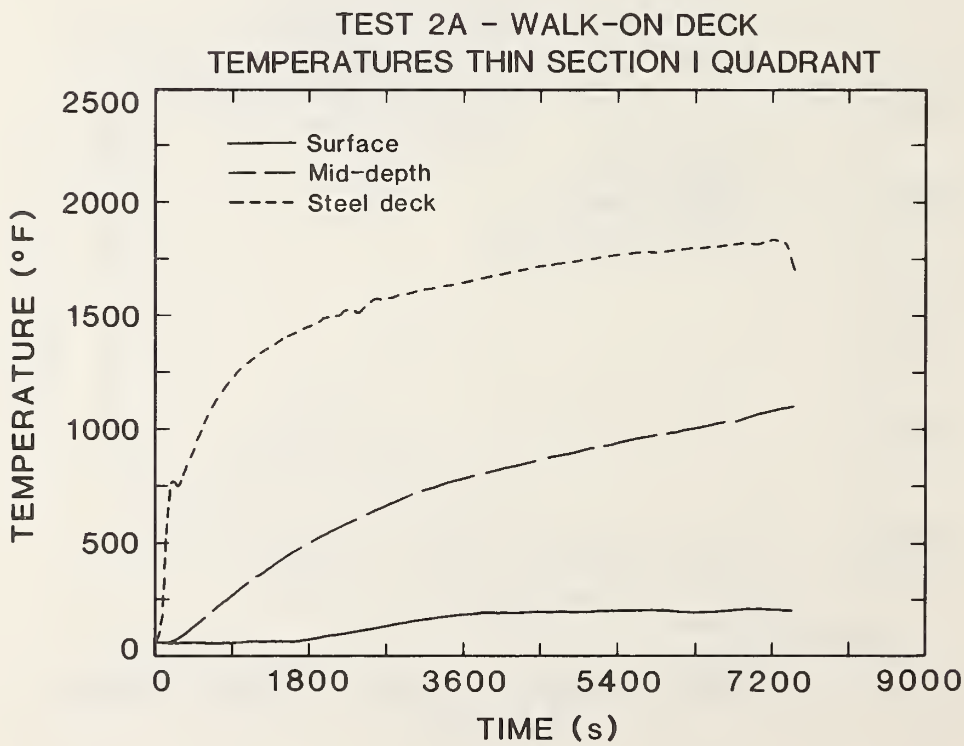


Figure 101. Walk-on deck temperatures thin section quadrant I, test 2A

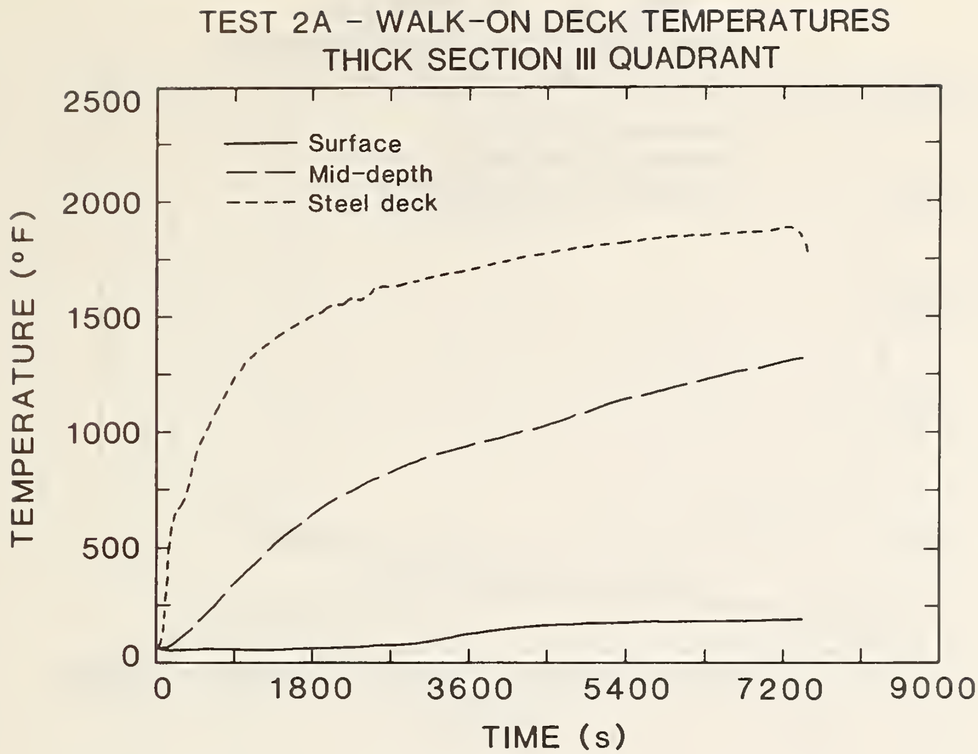


Figure 102. Walk-on deck temperatures thick section quadrant III, test 2A

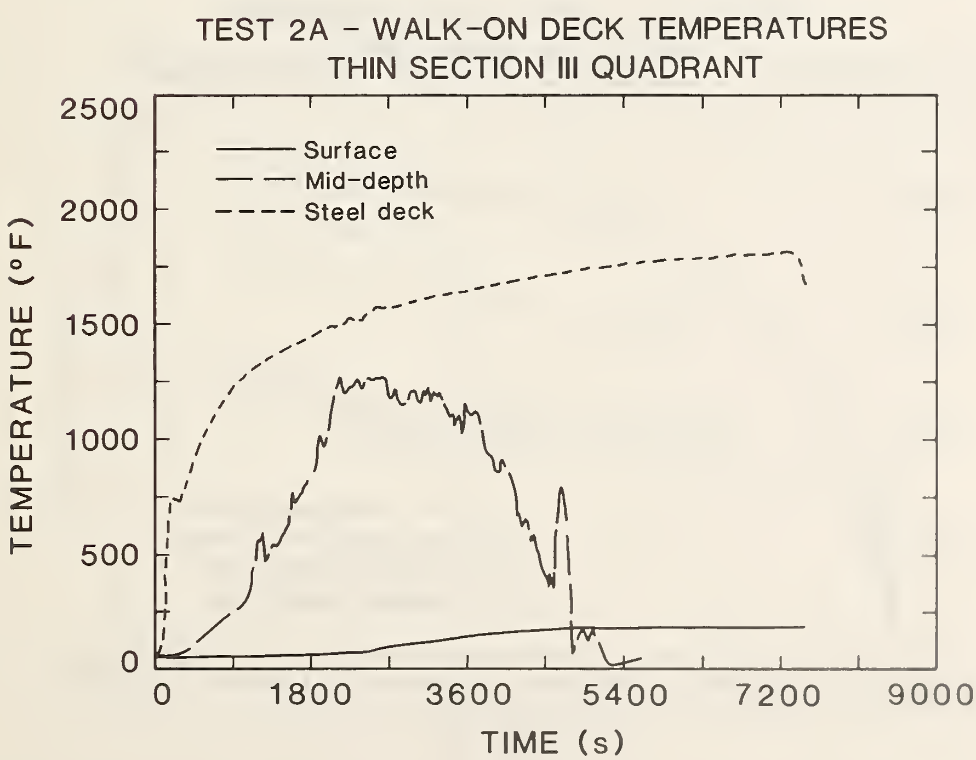


Figure 103. Walk-on deck temperatures thin section quadrant III, test 2A

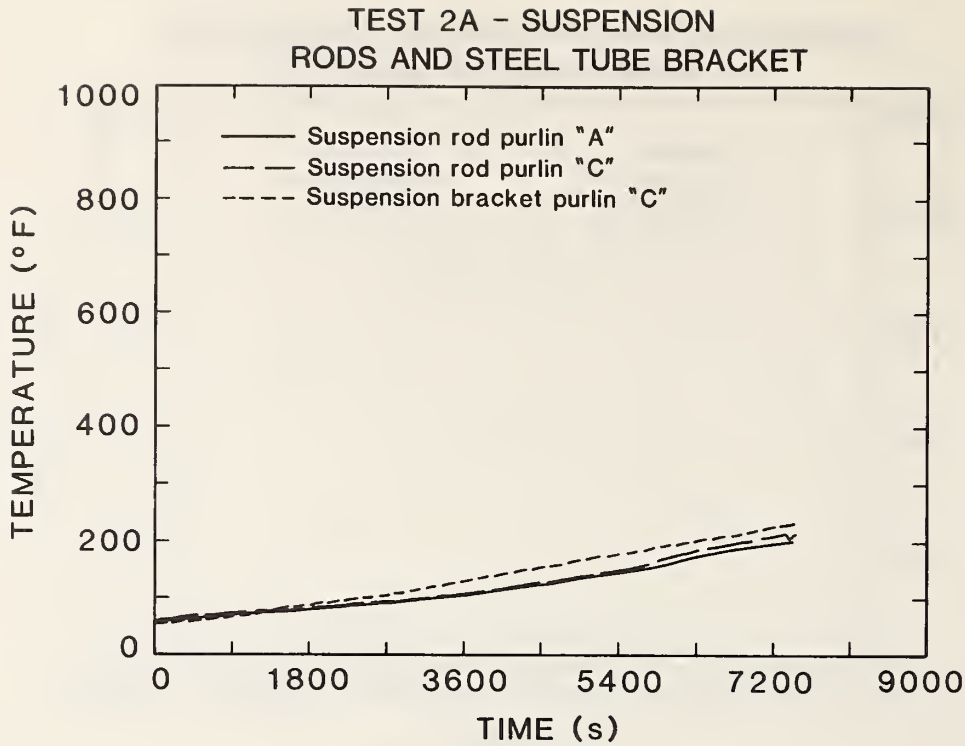


Figure 104 Temperatures for suspension rods and steel tube bracket, test 2A

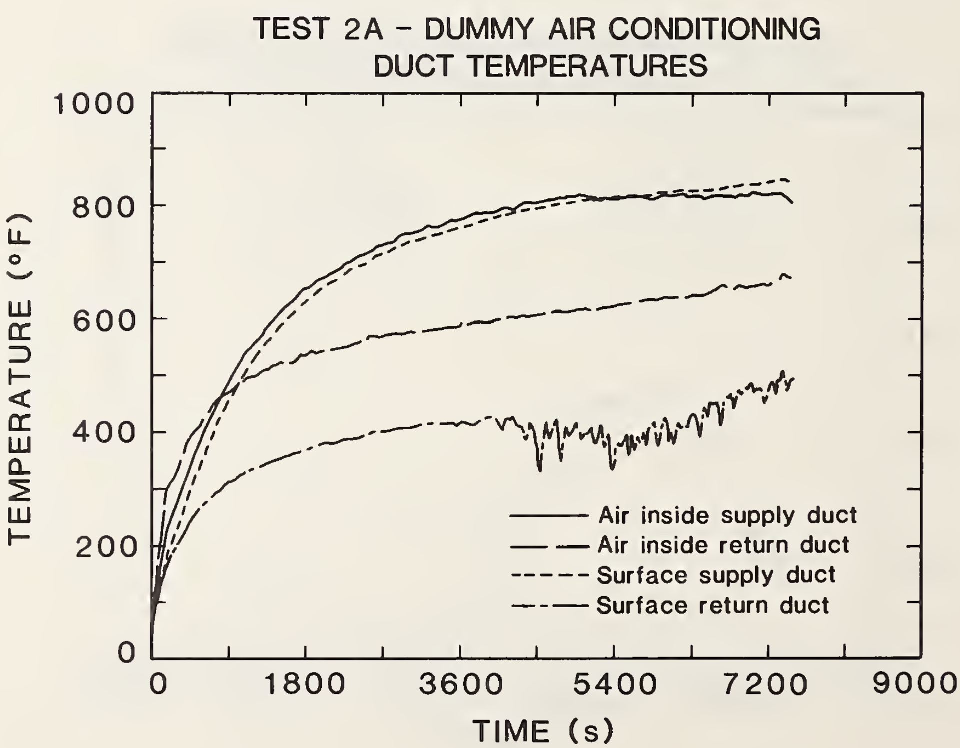


Figure 105. Dummy air conditioning duct temperatures, test 2A

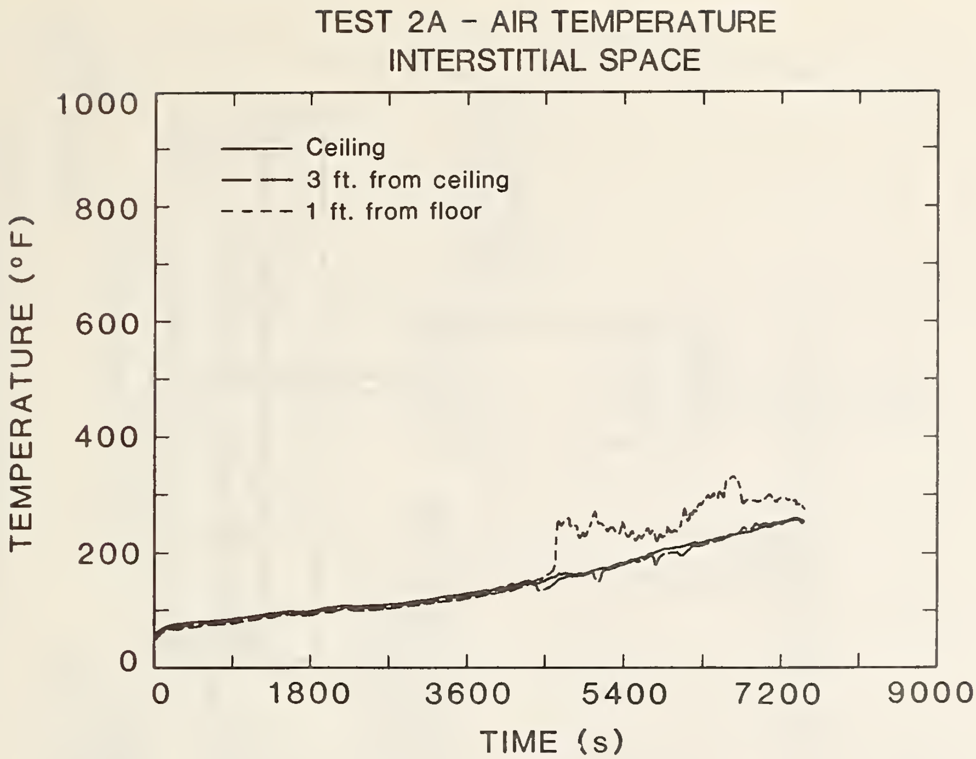


Figure 106. Interstitial space air temperatures, test 2A

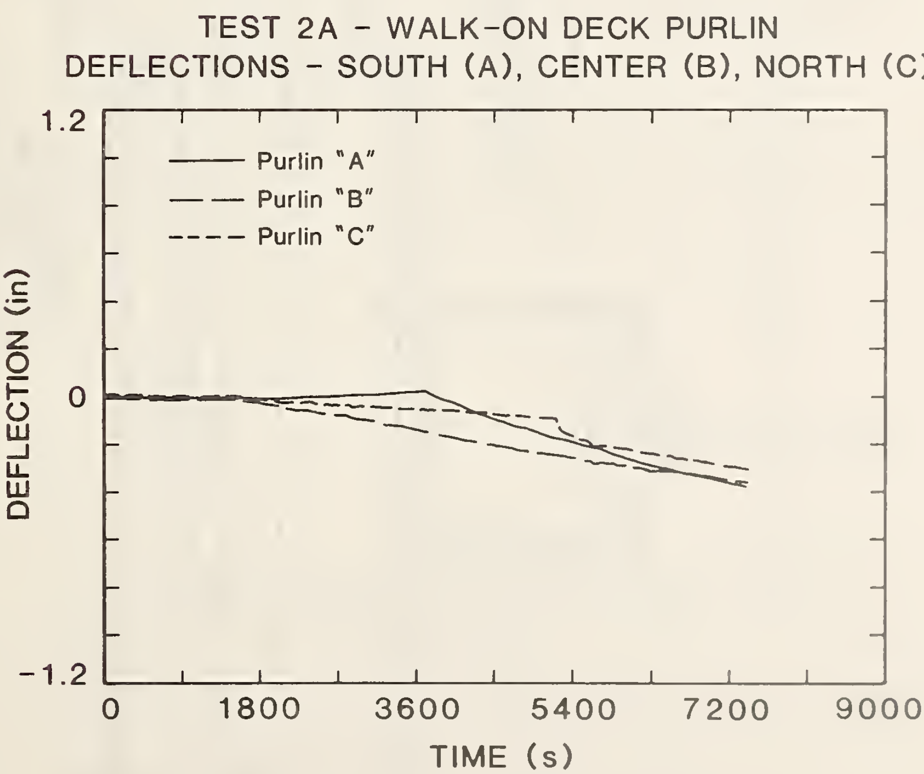


Figure 107. Walk-on deck purlin deflections, test 2A

POURED GYPSUM
WALK-ON DECK

PLATFORM
DESIGN LOAD
LIVE LOAD 25 LBS/FT^2
EQUIPMENT LOAD 15 LBS/FT^2

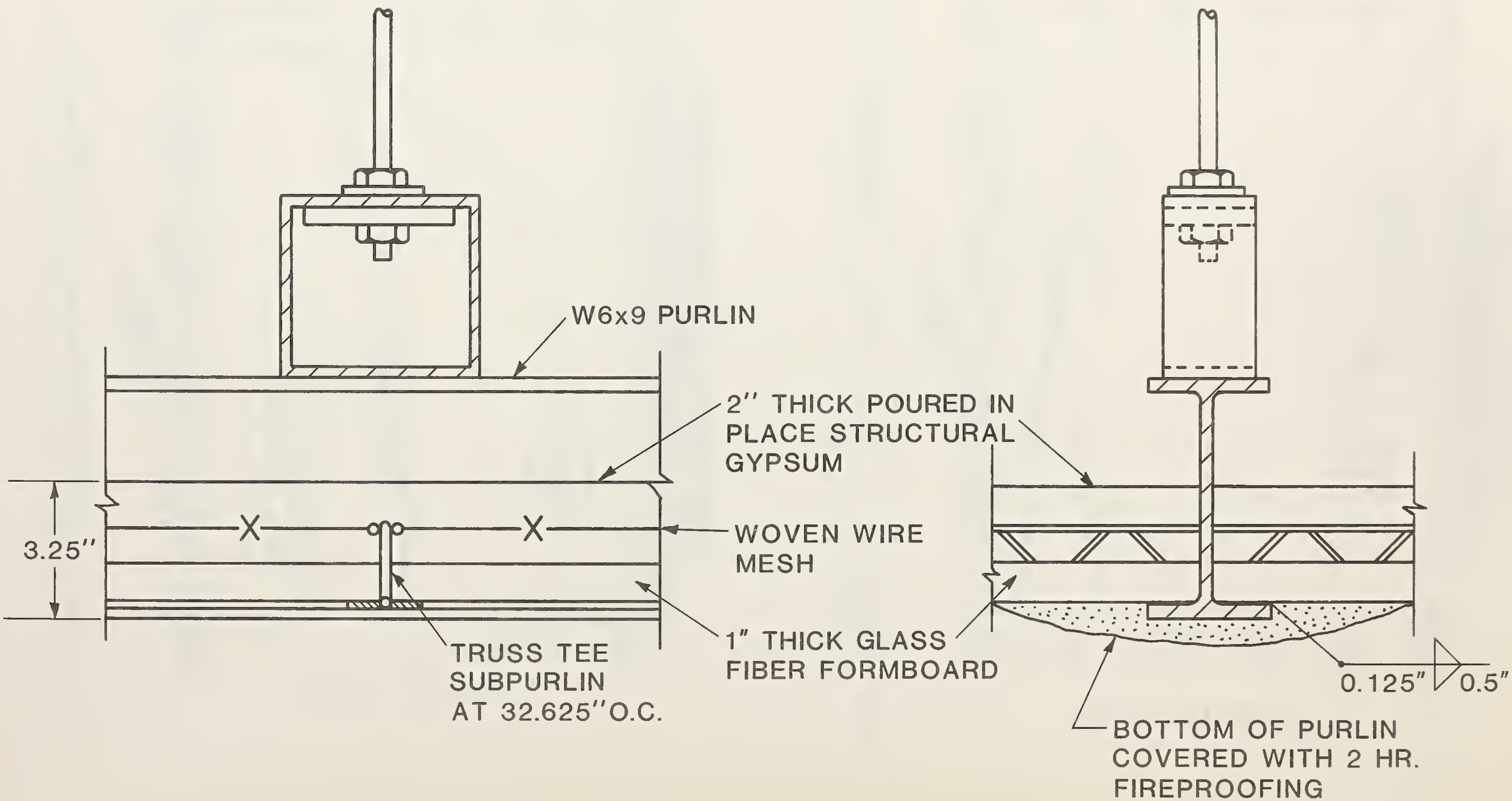


Figure 108. Construction details for poured gypsum walk-on deck system, test 2

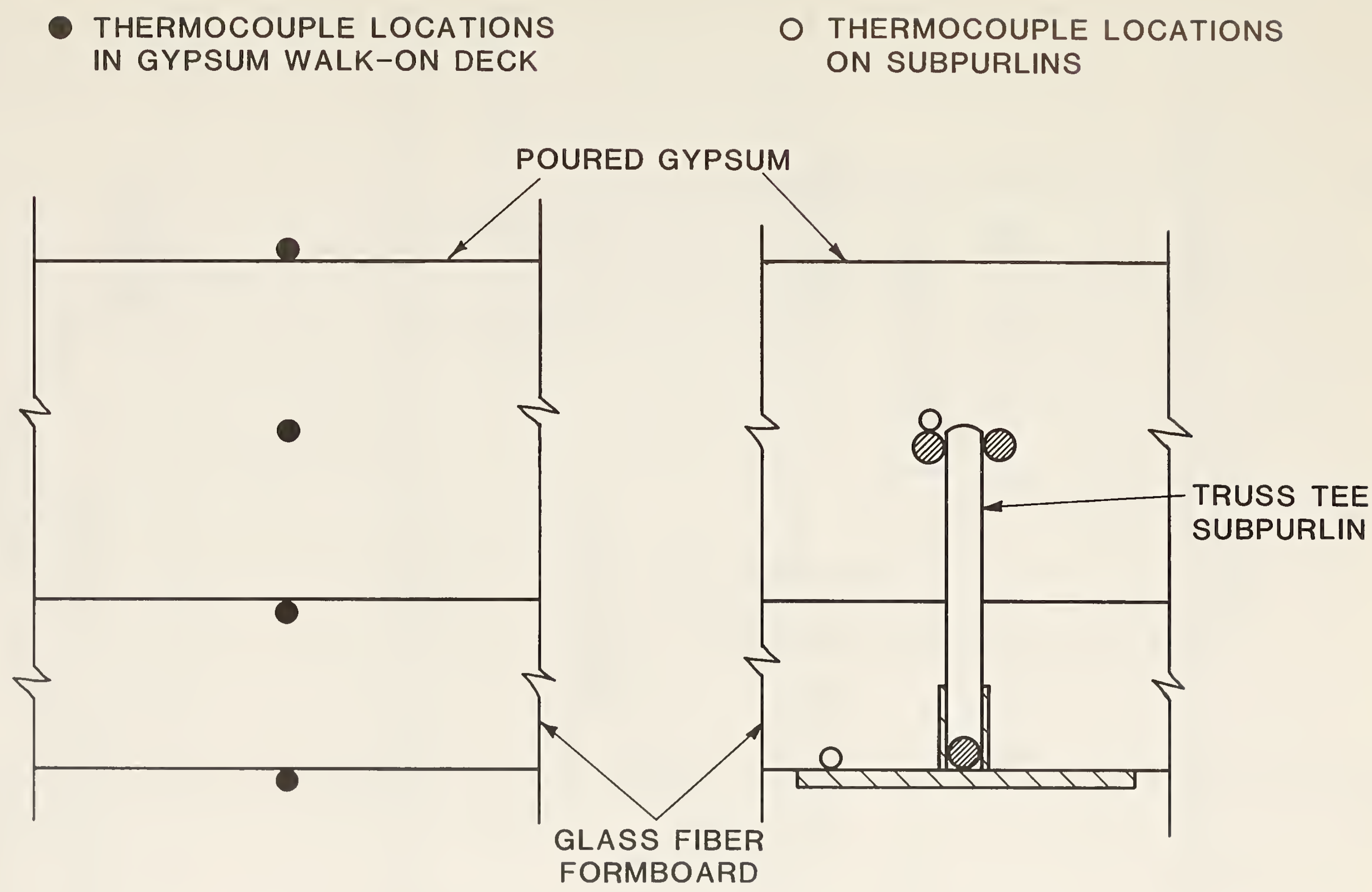


Figure 109(A). Thermocouple locations through section of gypsum walk-on deck system, test 3

Figure 109(B). Subpurlin temperature measurement points, test 3

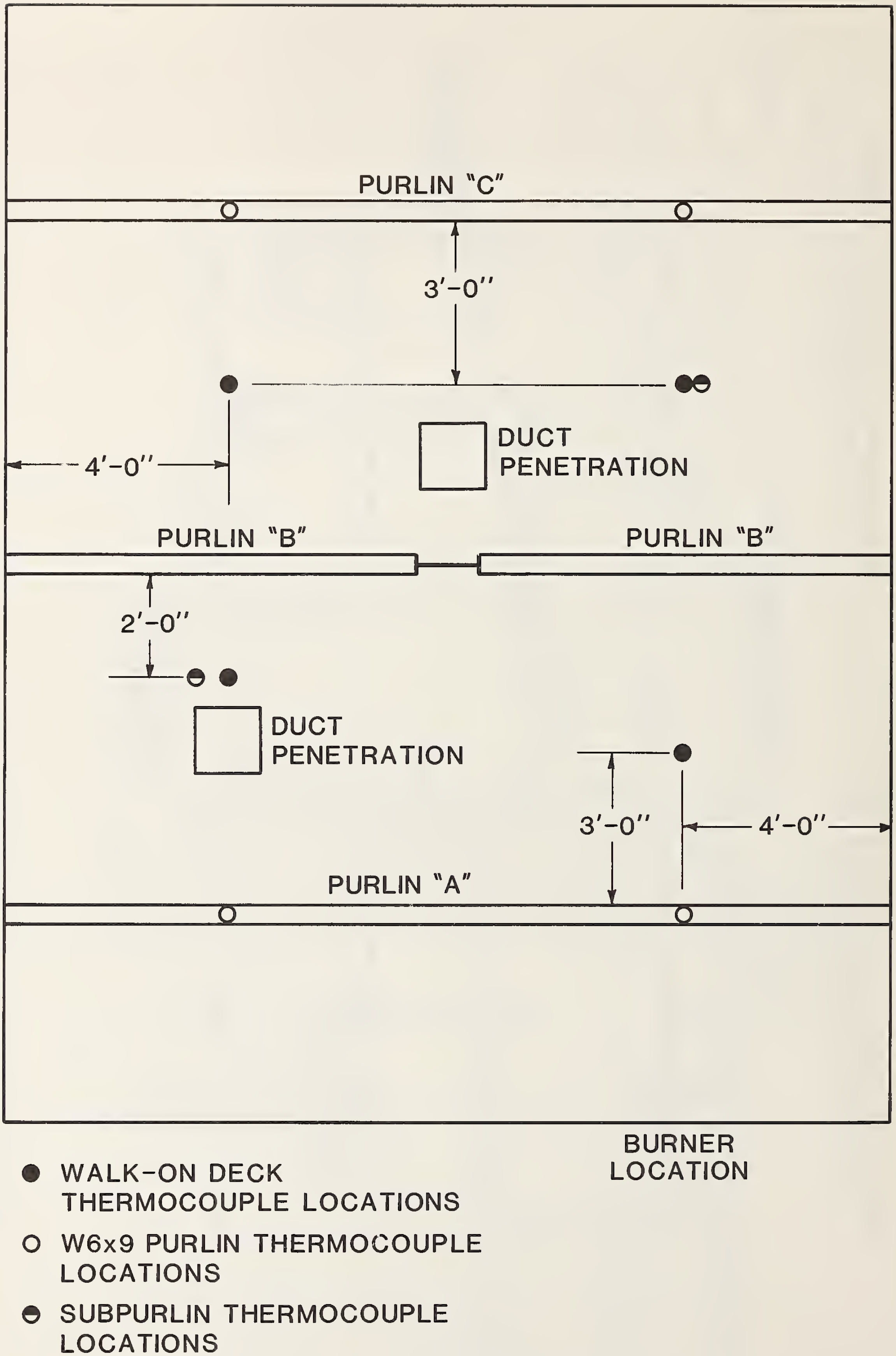


Figure 110. Locations for thermocouple sets in gypsum walk-on deck, test 3

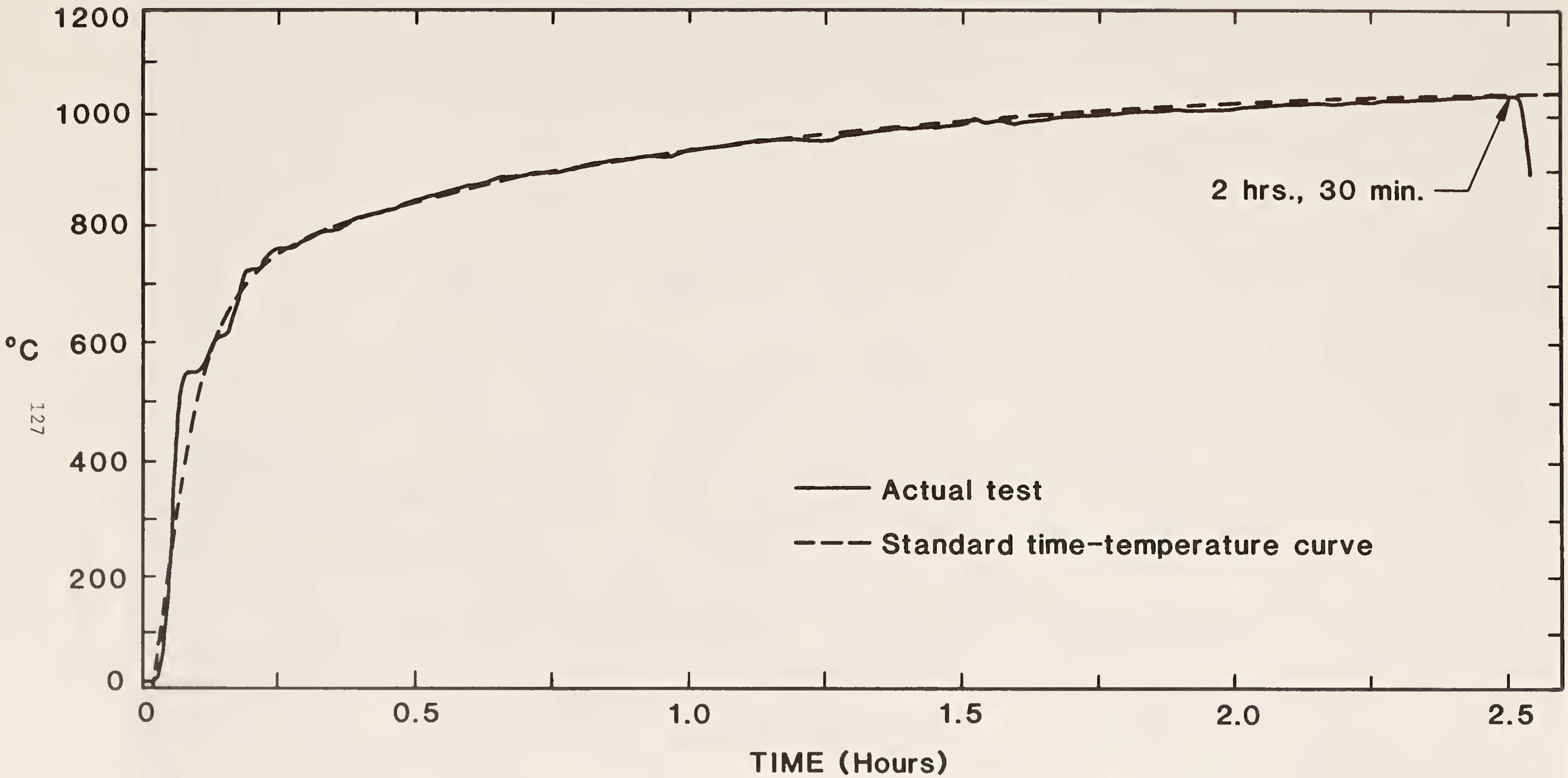


Figure 111. Chart record of average furnace temperature, test 3

Figure 112. Photograph showing bottom of gypsum walk-on deck after test 3

Figure 113. Photograph showing bent suspension rod in interstitial space, test 3

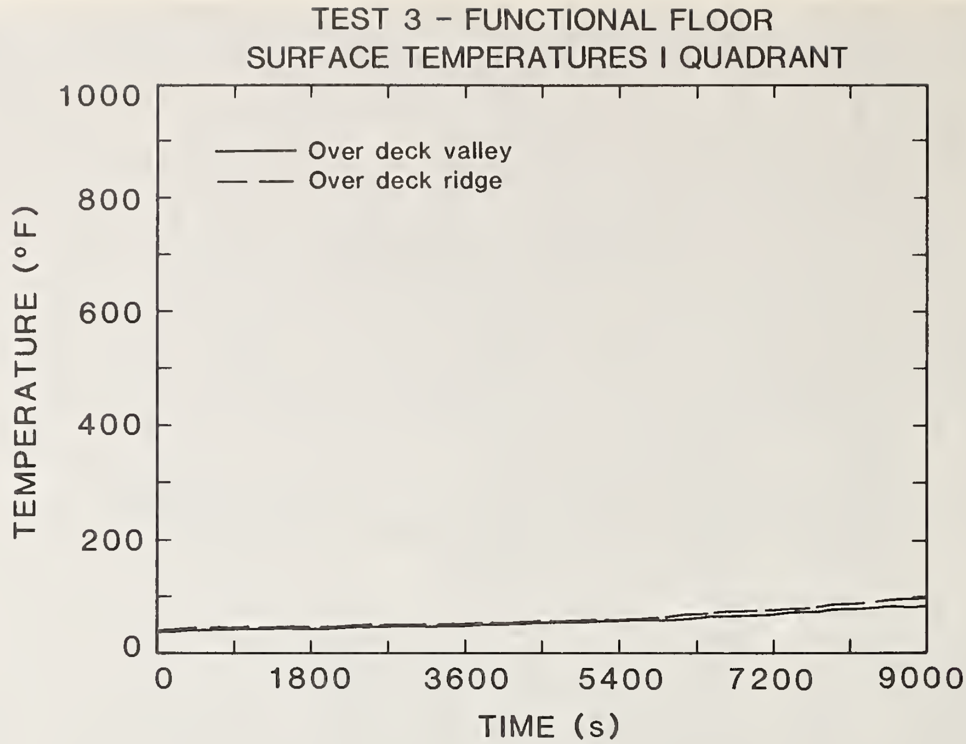


Figure 114. Functional floor surface temperatures quadrant I, test 3

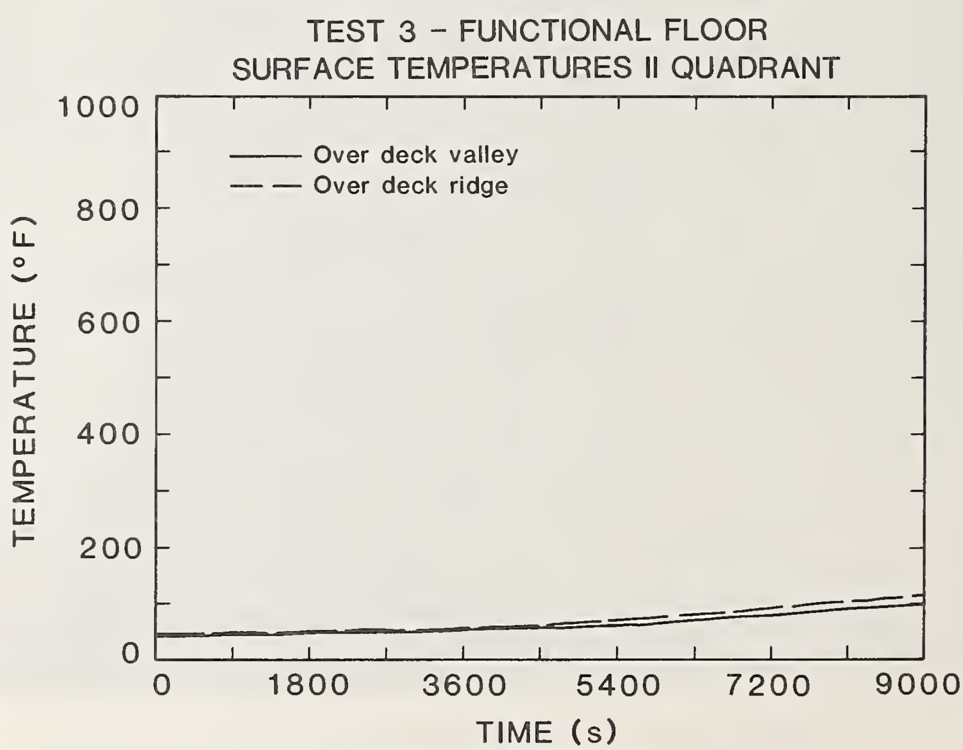


Figure 115. Functional floor surface temperatures quadrant II, test 3

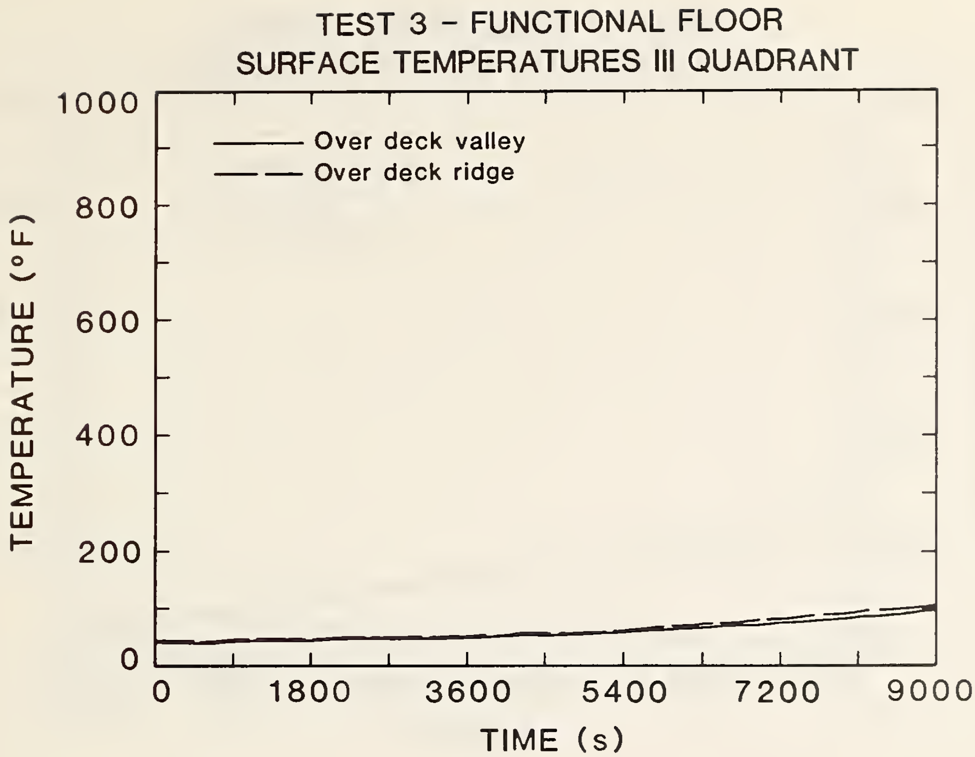


Figure 116. Functional floor surface temperatures quadrant III, test 3

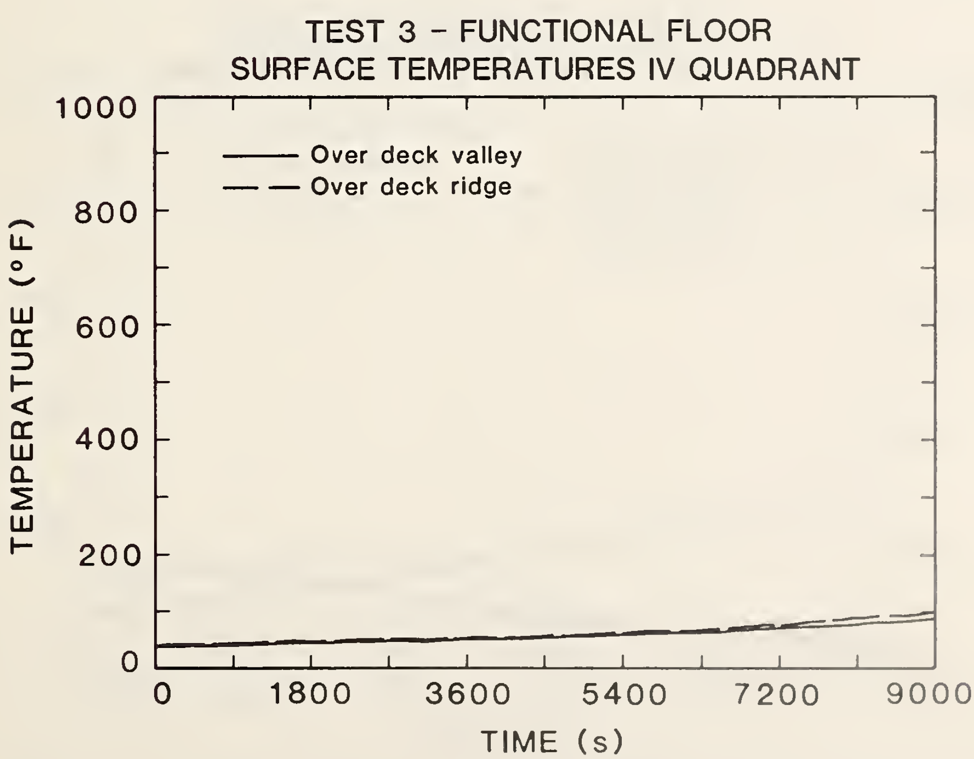


Figure 117. Functional floor surface temperatures quadrant IV, test 3

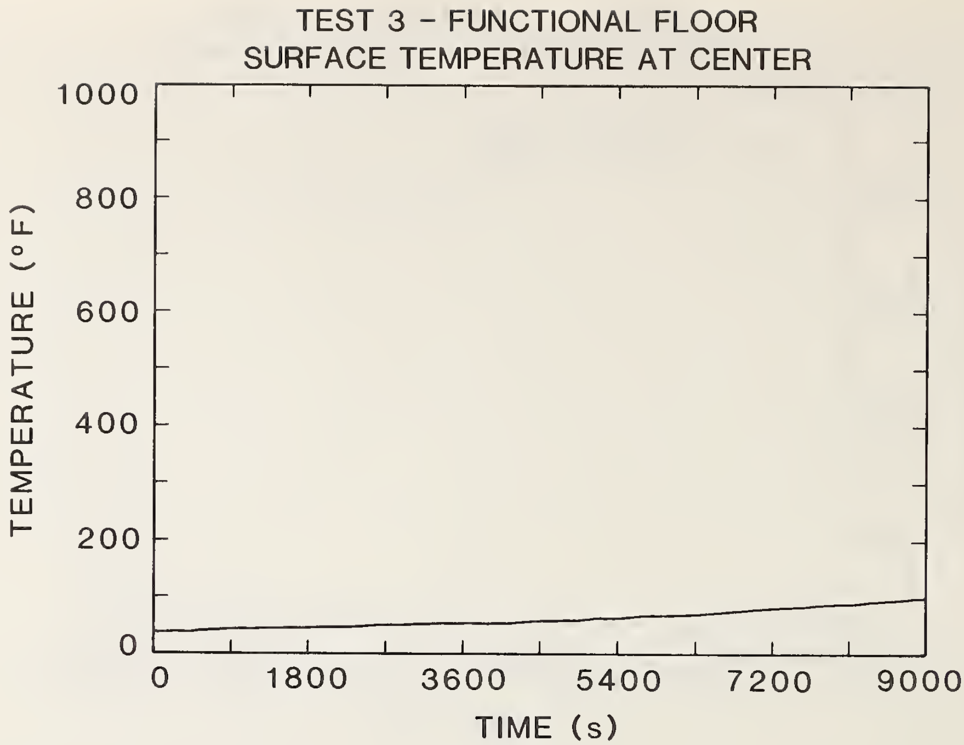


Figure 118. Functional floor surface temperature center of test bay, test 3

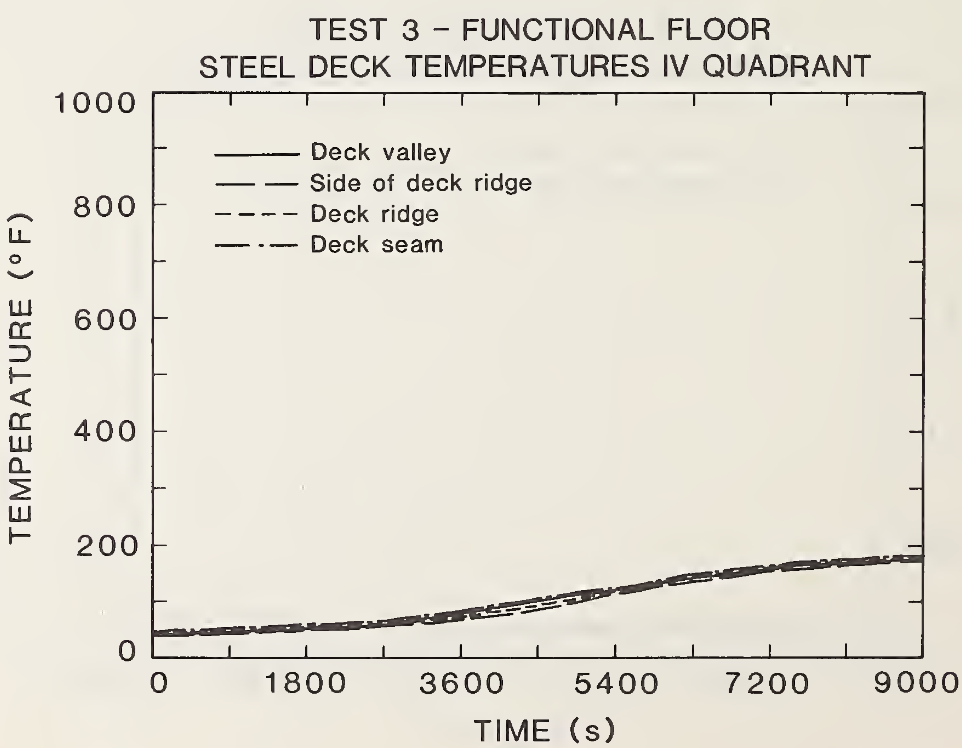


Figure 119. Functional floor steel deck temperatures quadrant IV, test 3

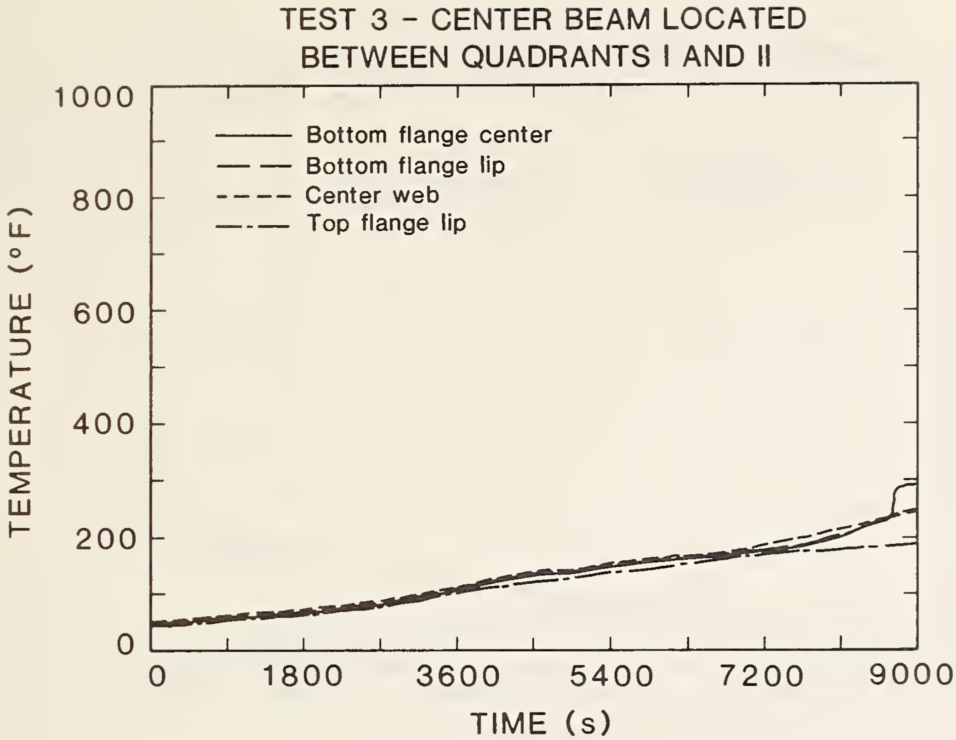


Figure 120. Temperatures for center beam supporting the functional floor, center measurement point between quadrants I and II, test 3

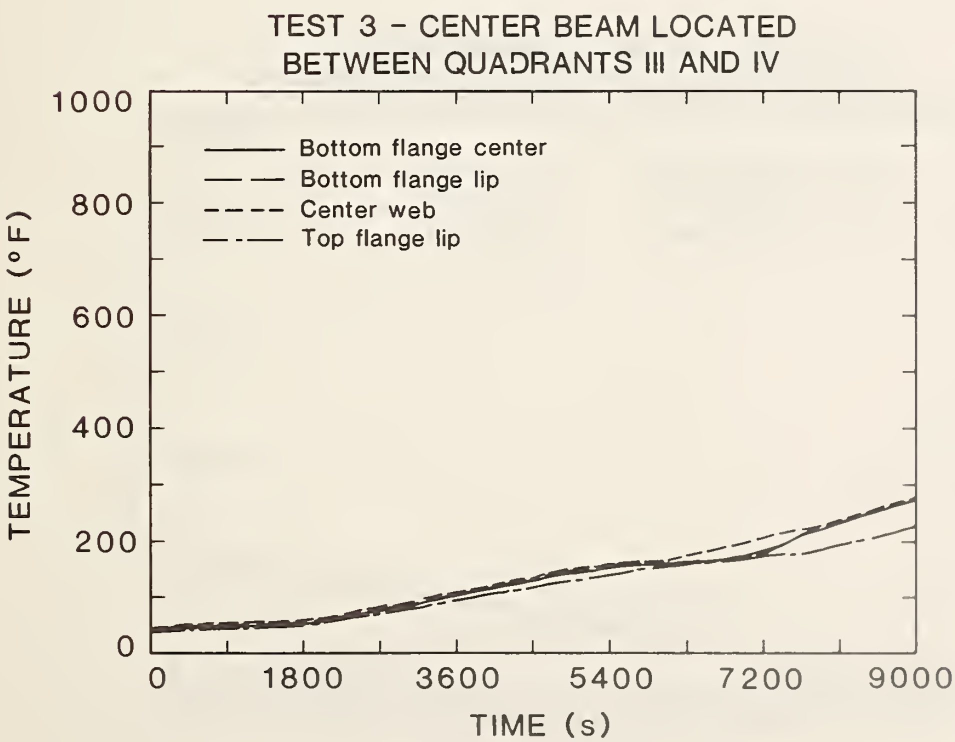


Figure 121. Temperatures for center beam supporting the functional floor, center measurement point between quadrants III and IV, test 3

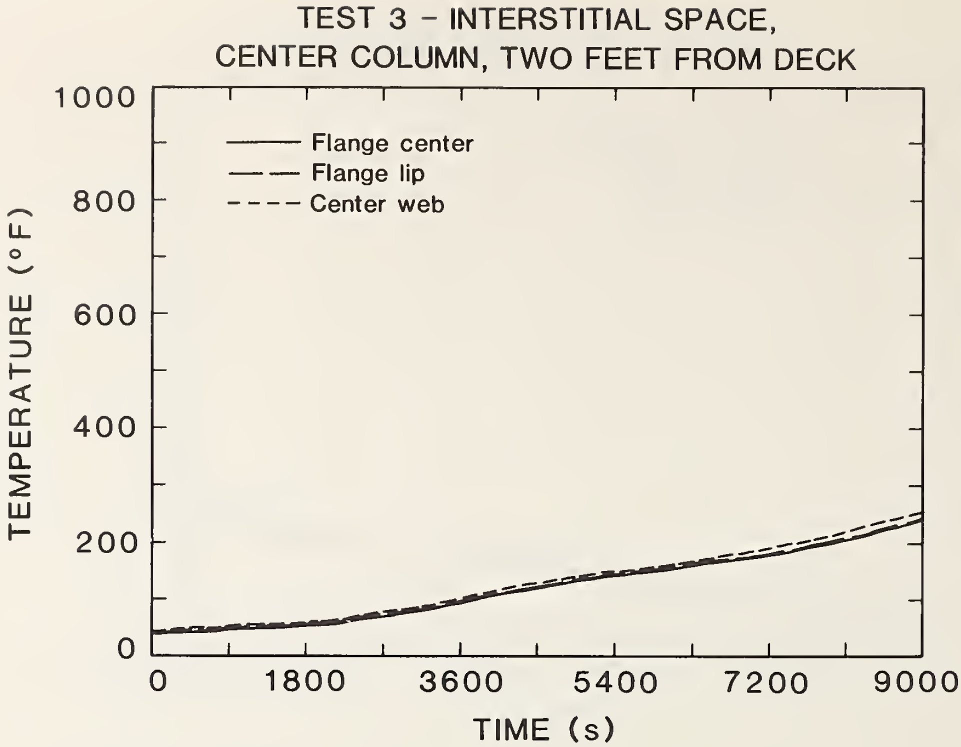


Figure 122. Center column temperatures in interstitial space at measurement point two feet above walk-on deck, test 3

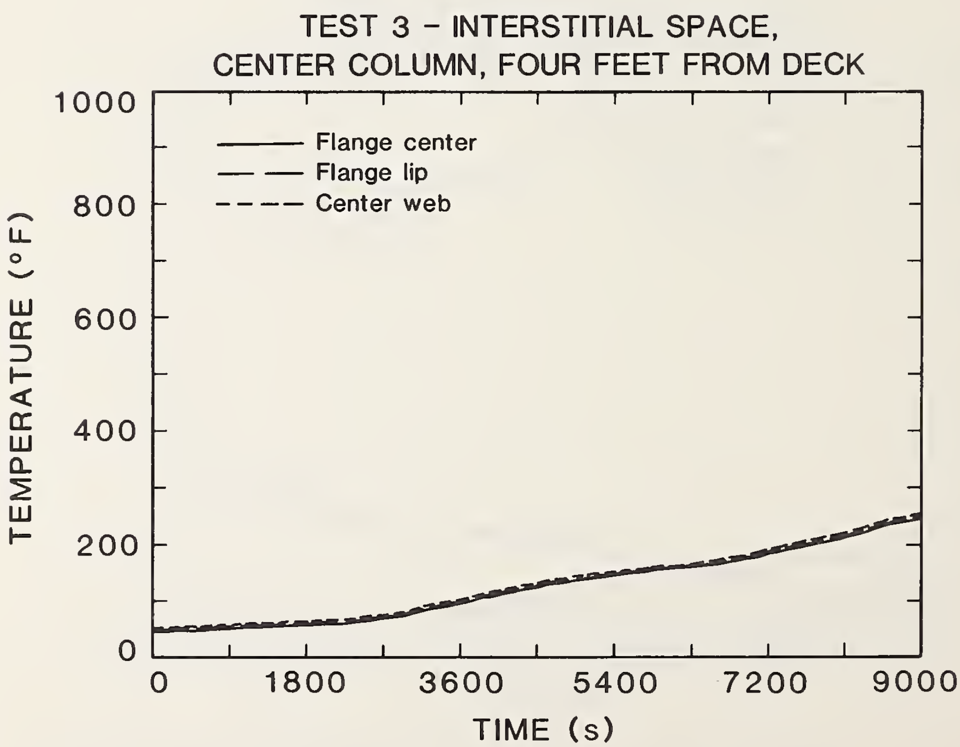


Figure 123. Center column temperatures in interstitial space at measurement point four feet above walk-on deck, test 3

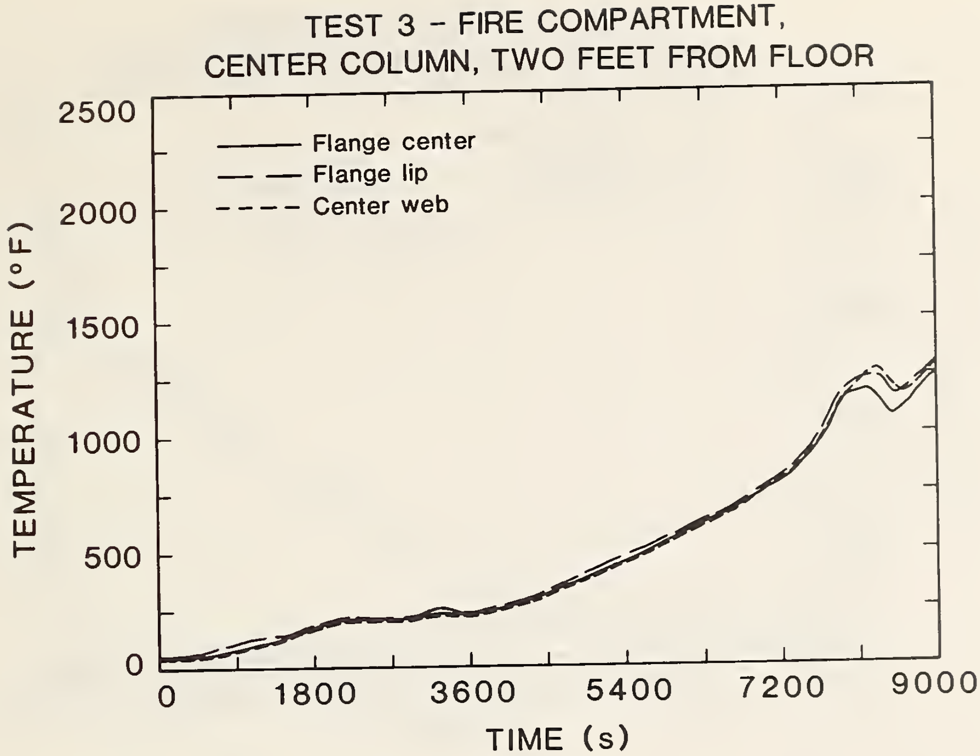


Figure 124. Column temperatures in furnace compartment two feet up from floor, test 3

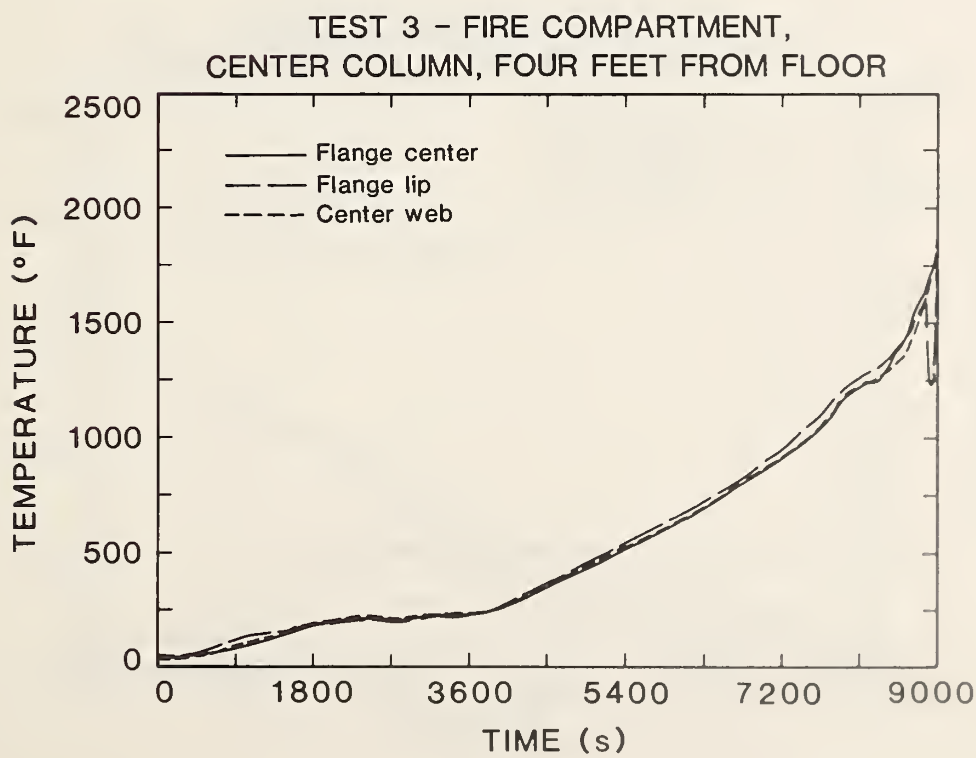


Figure 125. Column temperatures in furnace compartment four feet up from floor, test 3

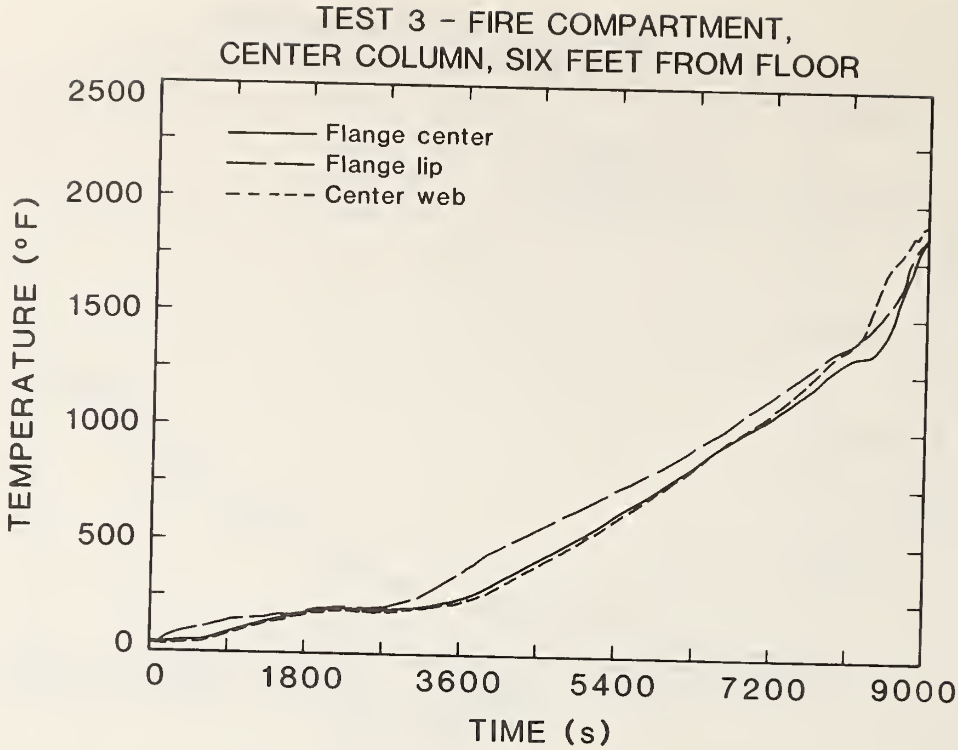


Figure 126. Column temperatures in furnace compartment six feet up from floor, test 3

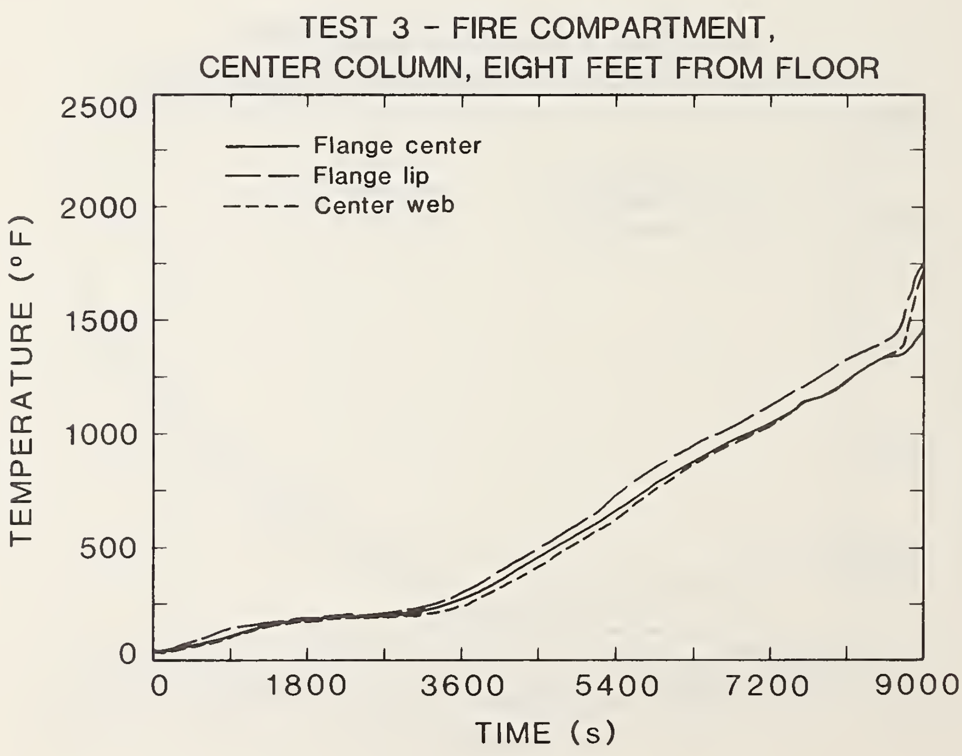


Figure 127. Column temperatures in furnace compartment eight feet up from floor, test 3

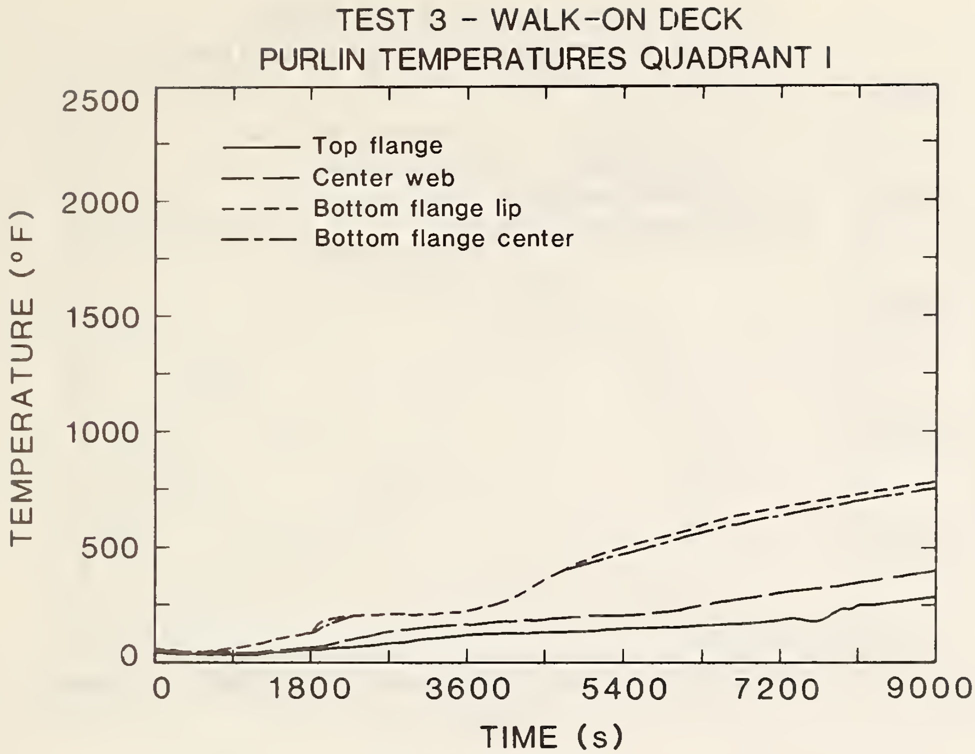


Figure 128. Walk-on deck purlin temperature quadrant I, test 3

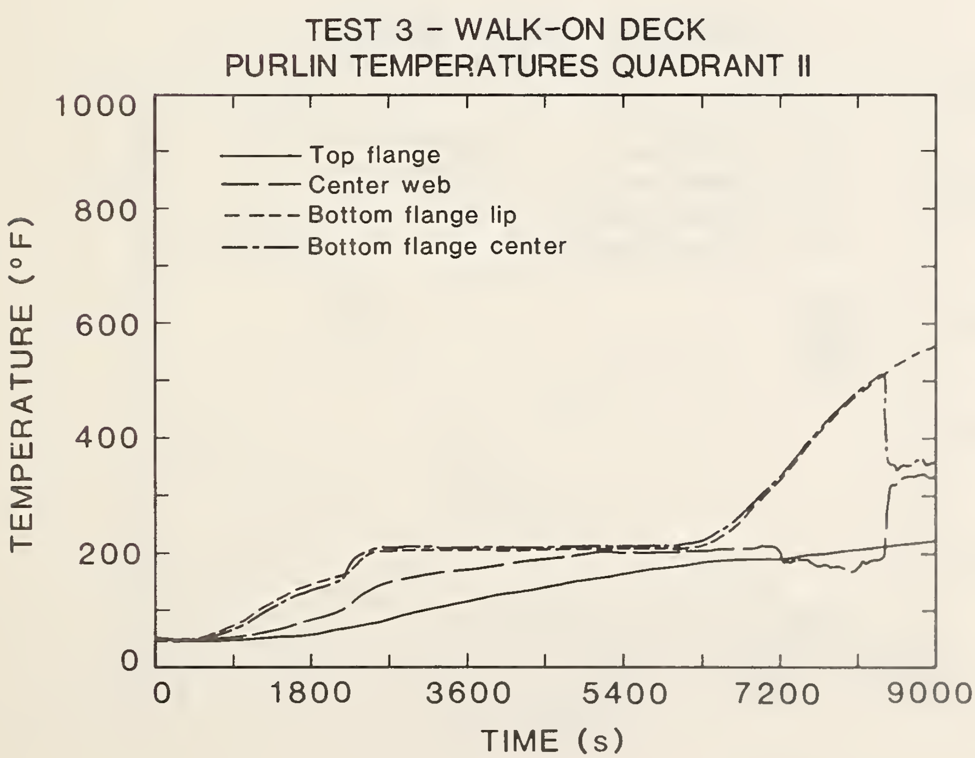


Figure 129. Walk-on deck purlin temperature quadrant II, test 3

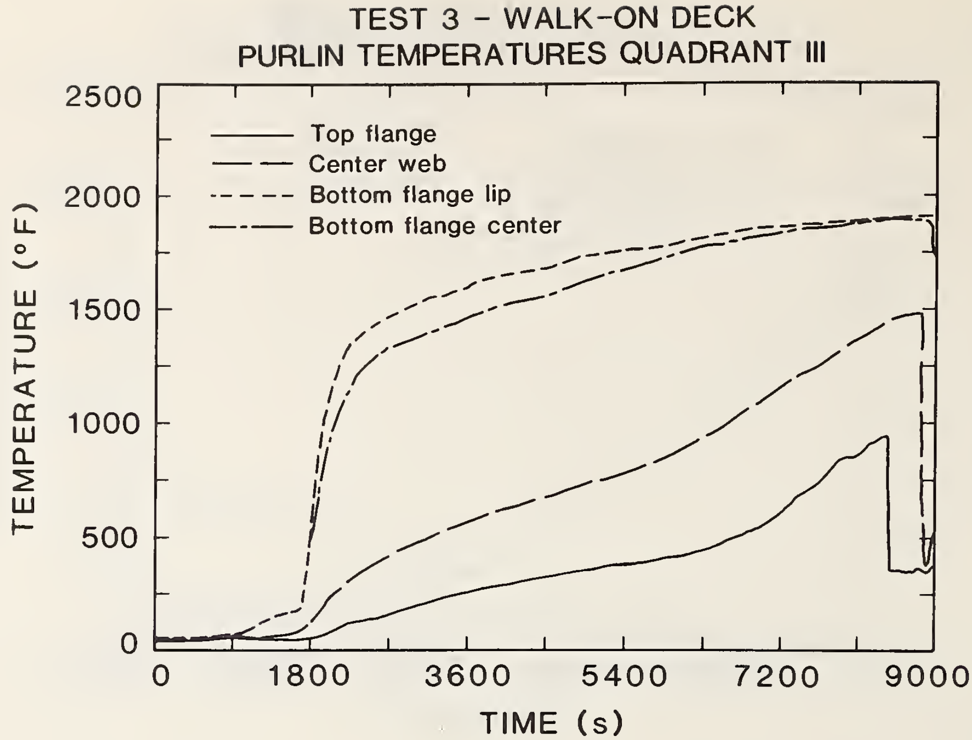


Figure 130. Walk-on deck purlin temperature quadrant III, test 3

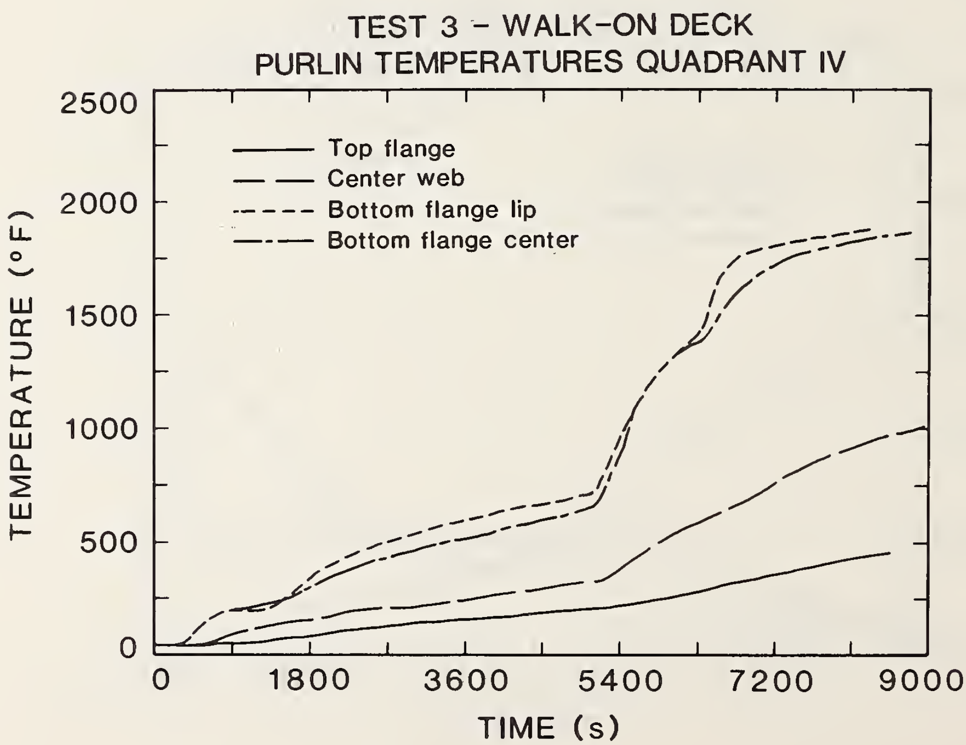


Figure 131. Walk-on deck purlin temperature quadrant IV, test 3

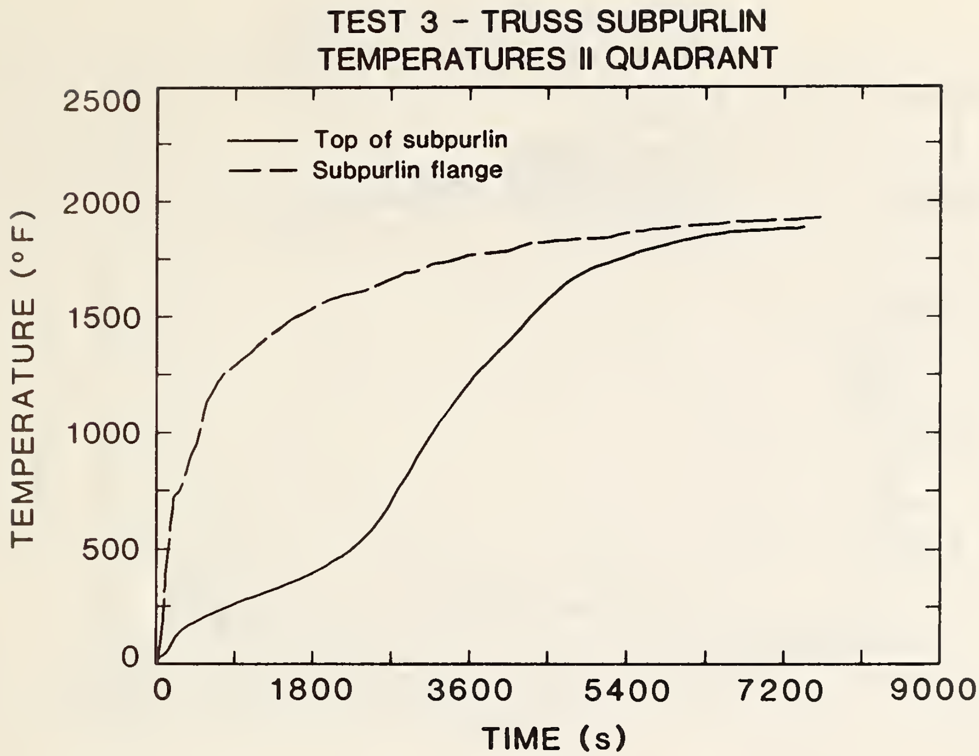


Figure 132. Walk-on deck subpurlin temperature temperature quadrant II, test 3

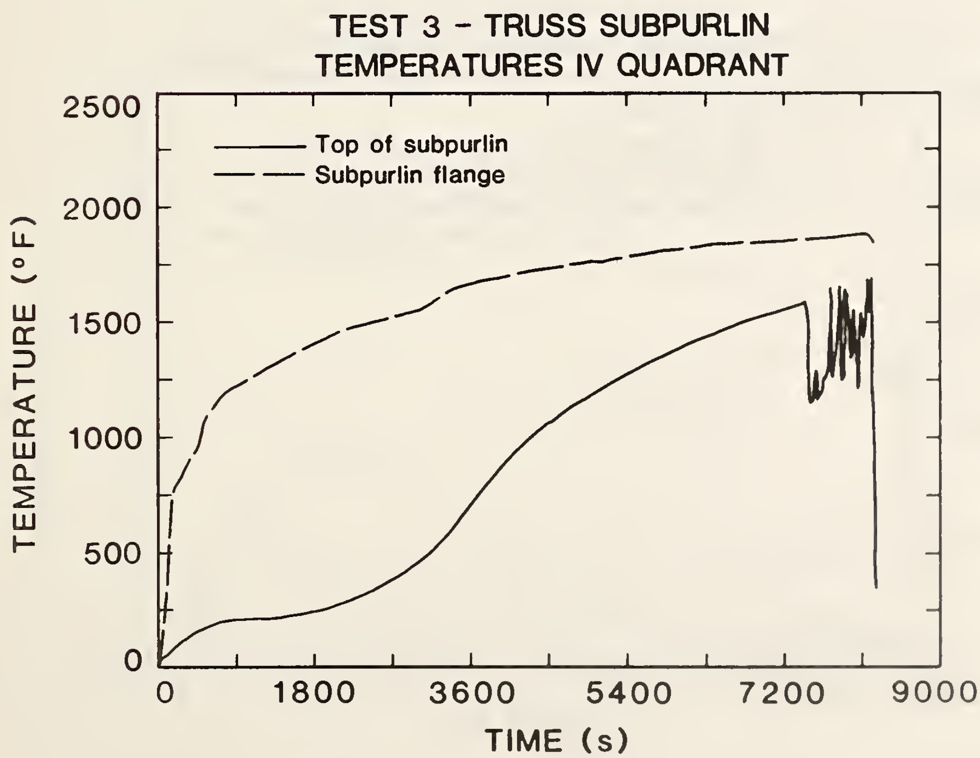


Figure 133. Walk-on deck subpurlin temperature quadrant IV, test 3

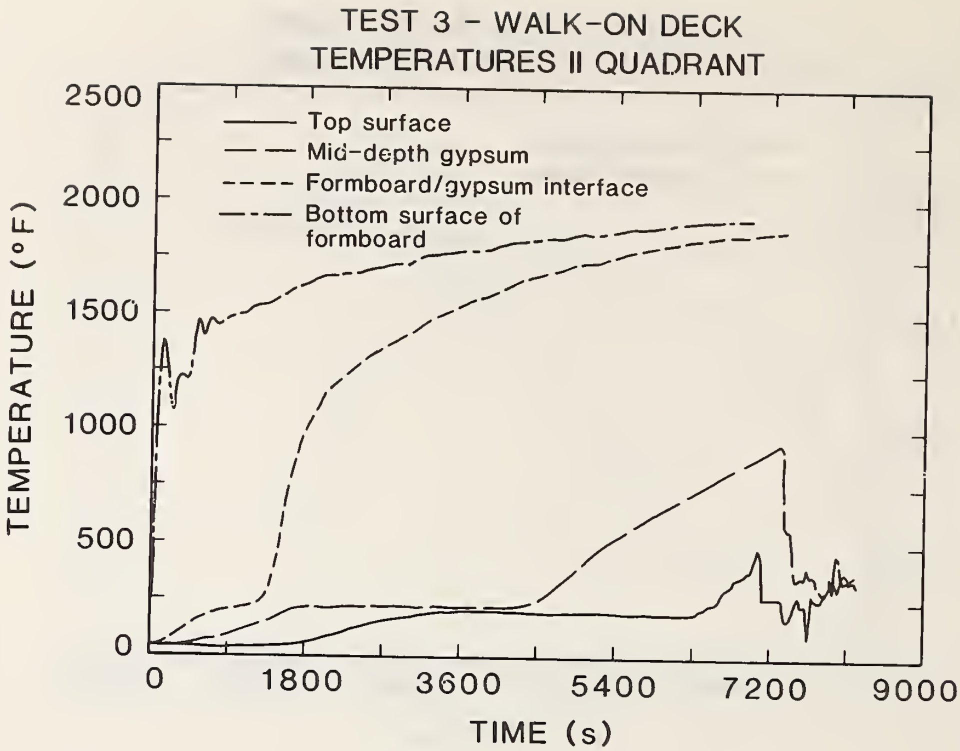


Figure 134. Walk-on deck temperatures quadrant II, test 3

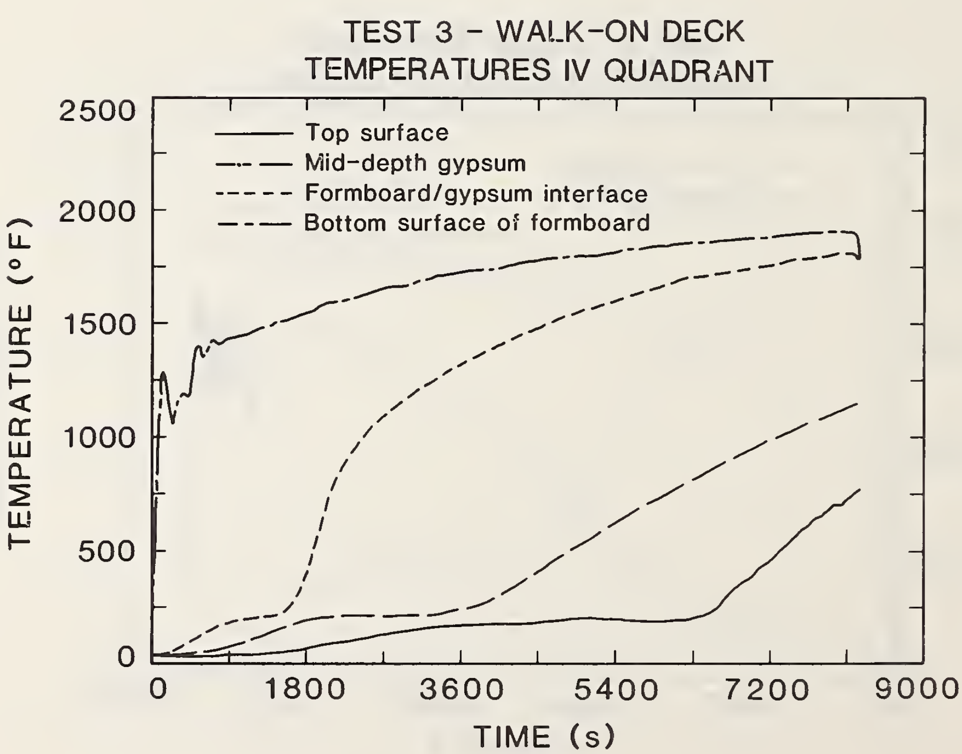


Figure 135. Walk-on deck temperatures quadrant IV, test 3

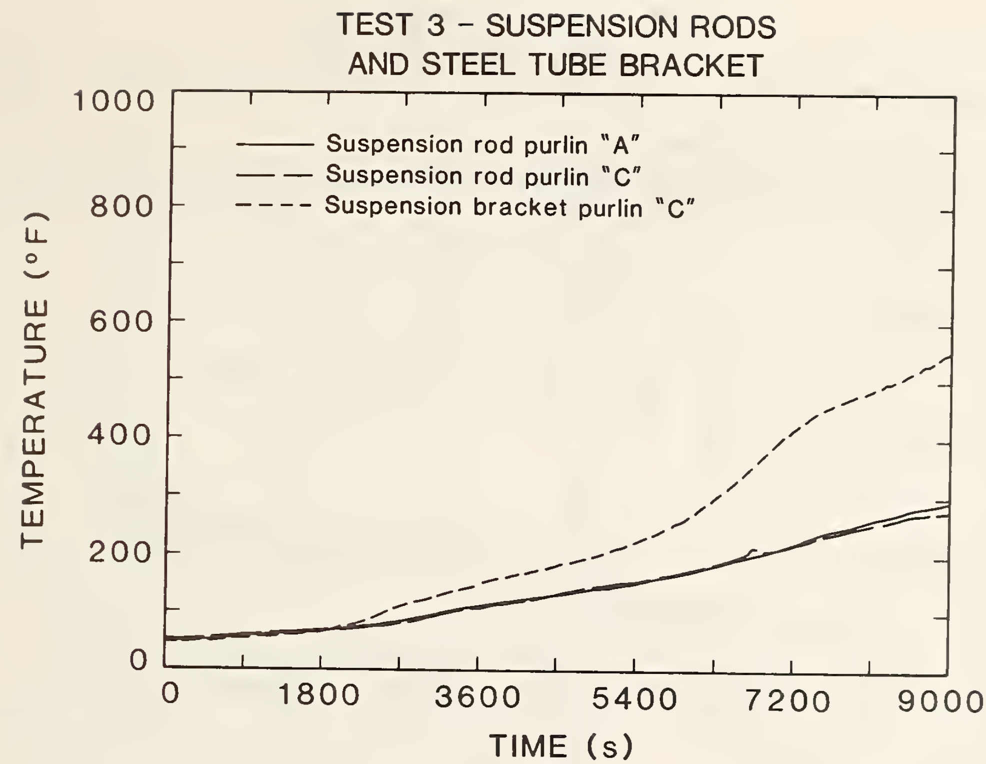


Figure 136. Temperatures for suspension rods and steel tube bracket, test 3

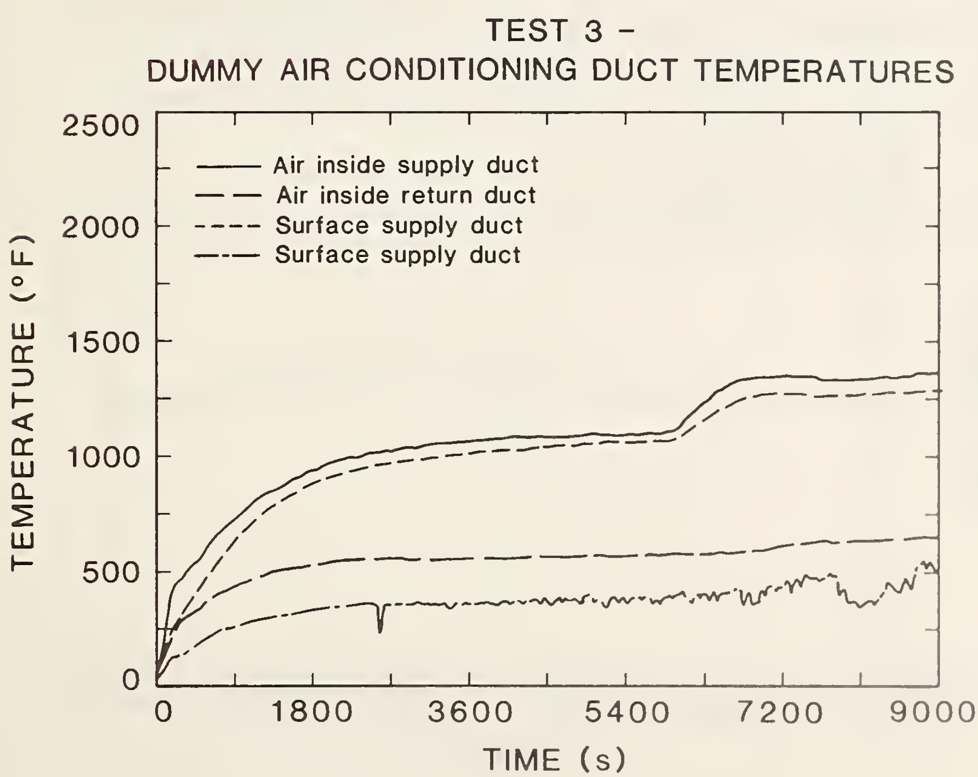


Figure 137. Dummy air conditioning duct temperatures, test 3

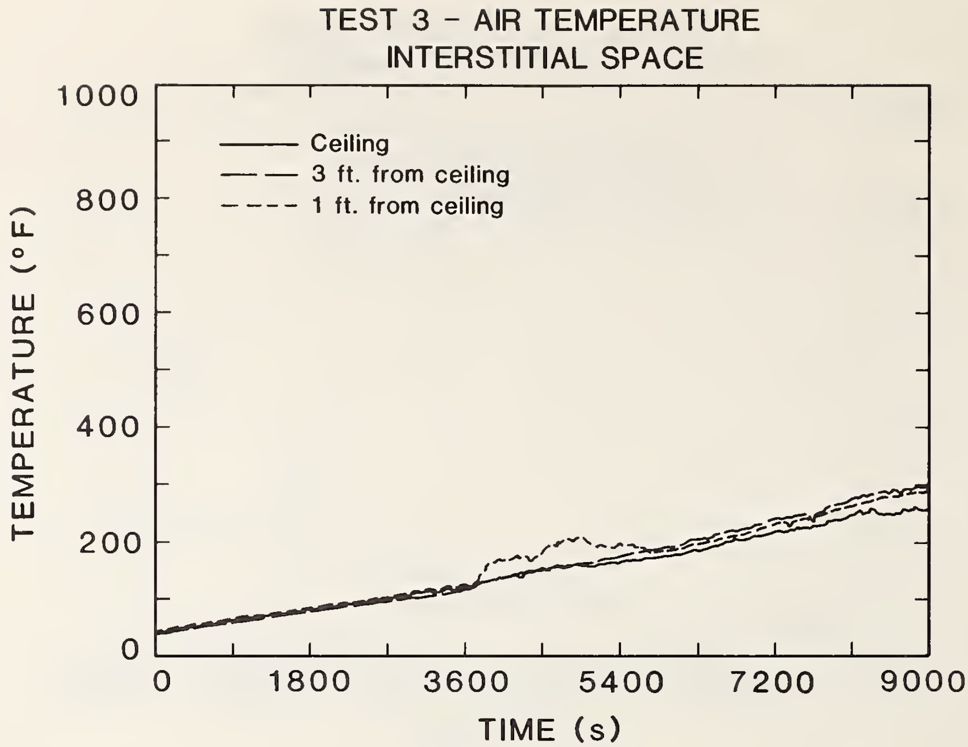


Figure 138. Interstitial space air temperatures, test 3

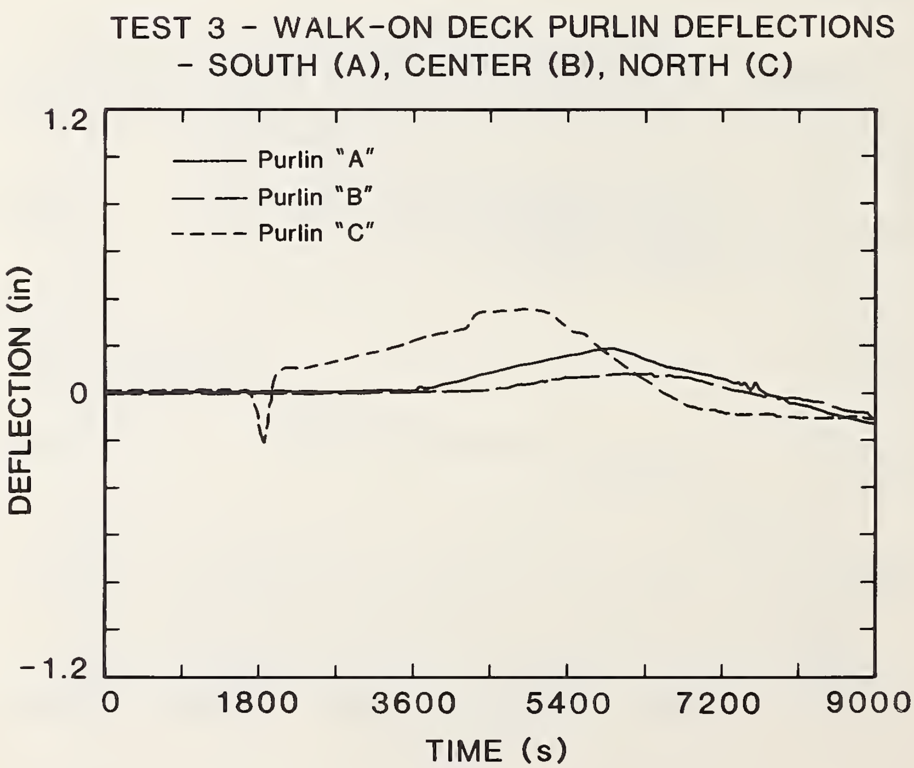


Figure 139. Walk-on deck purlin deflections, test 3

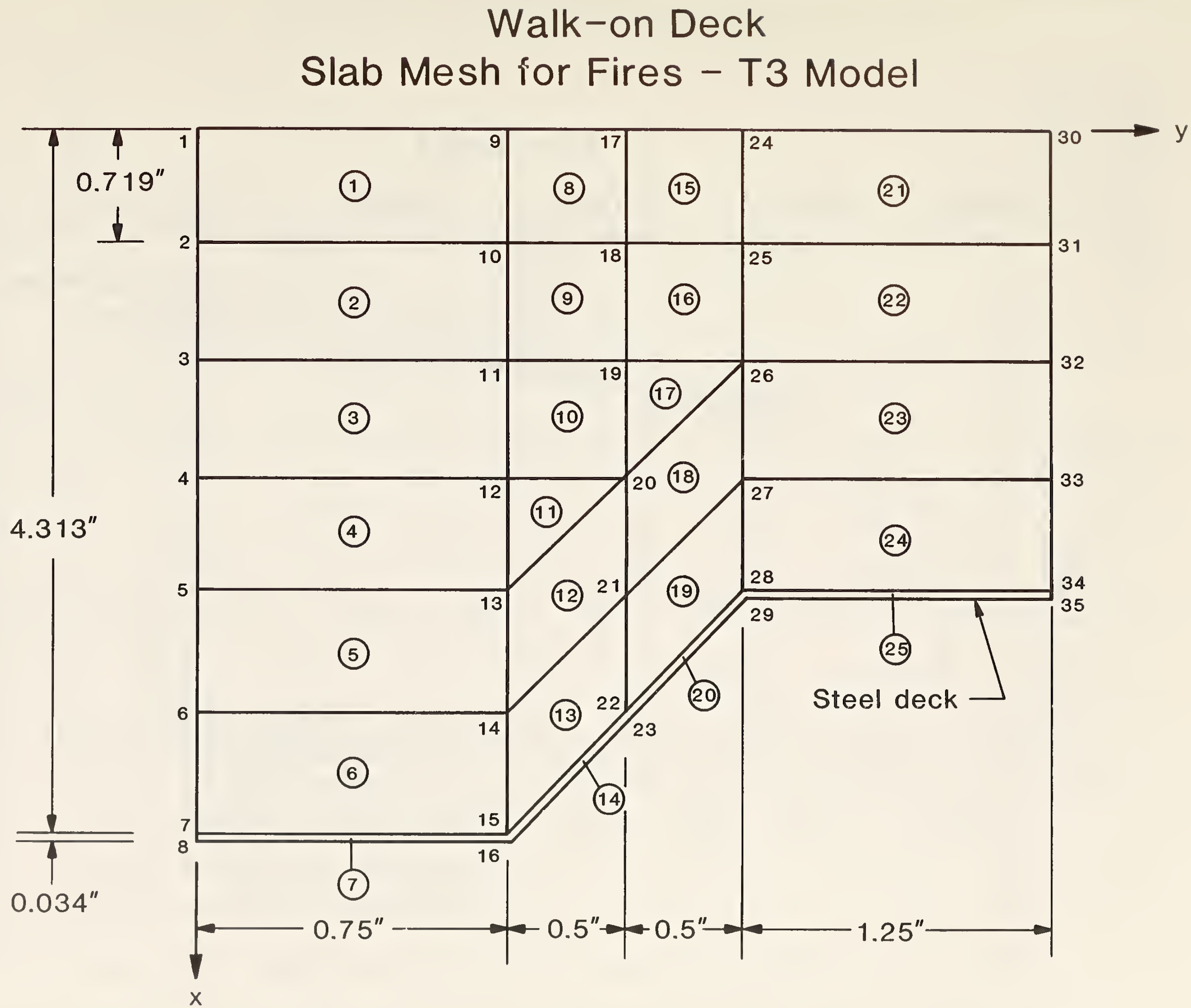


Figure 140. Lightweight concrete walk-on deck node and element locations for FIRES-T3 model

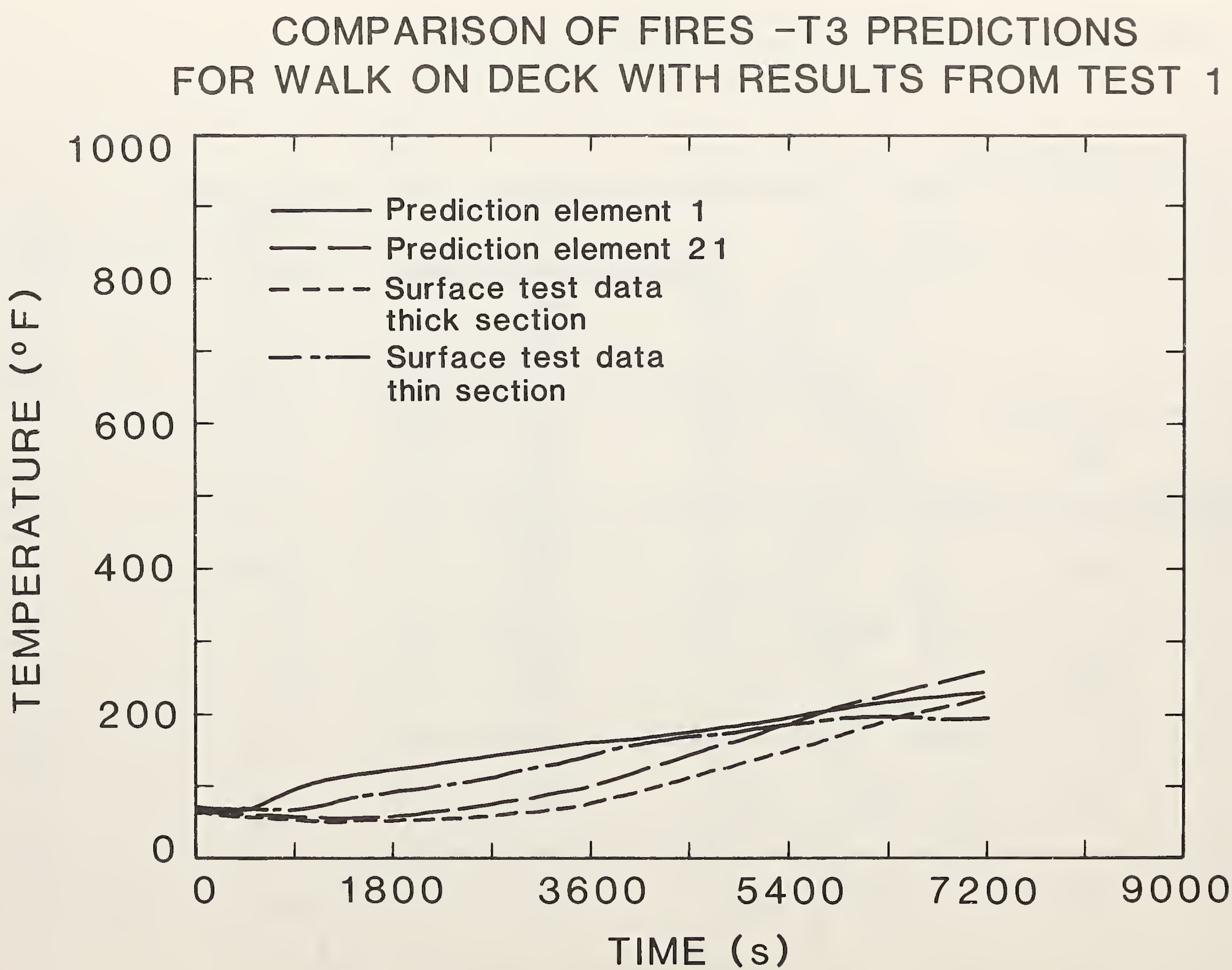


Figure 141. Comparison of FIRES-T3 predictions for walk-on deck with results from test 1

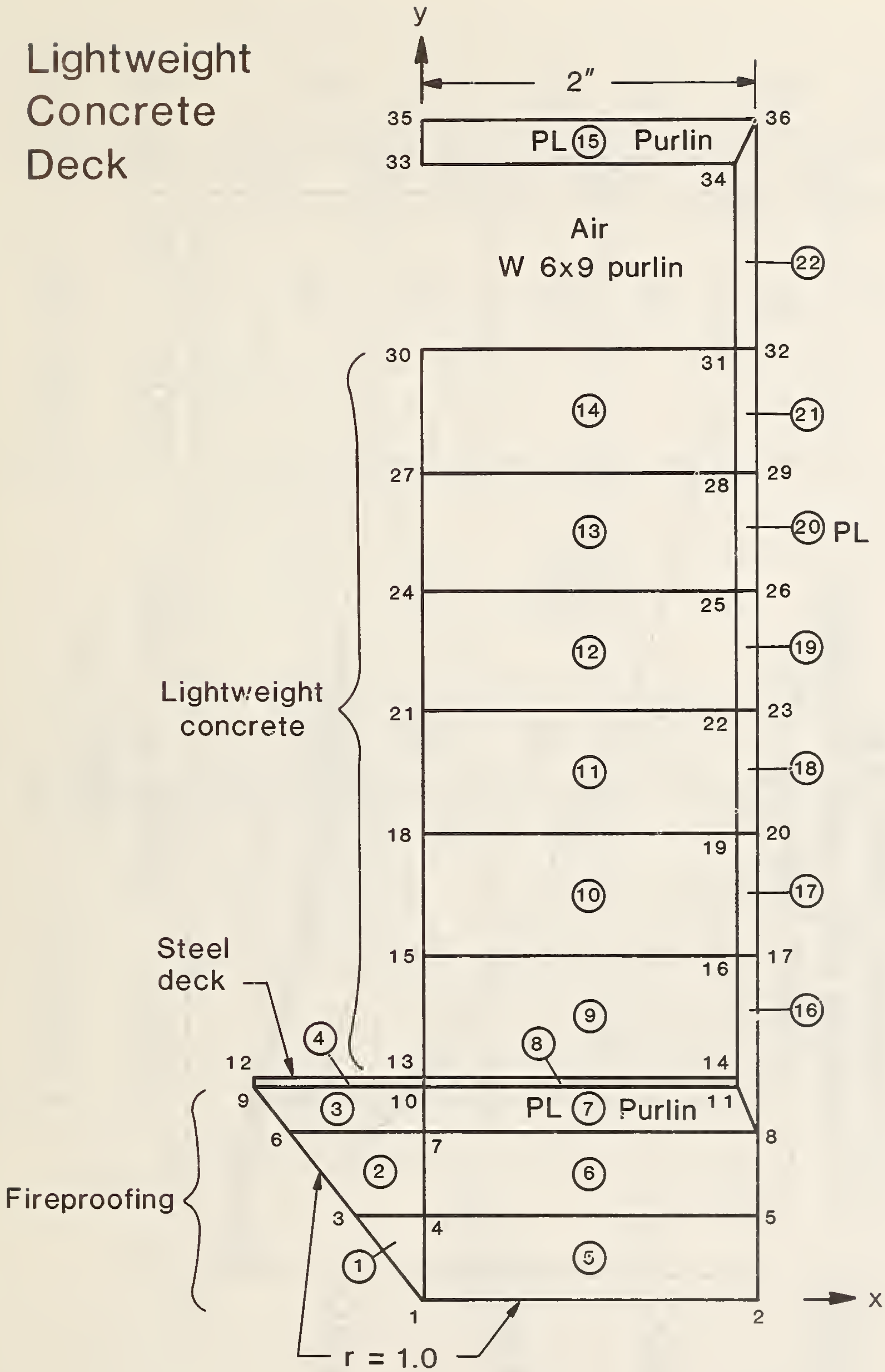


Figure 142. Node and element locations for fireproofed purlins in lightweight concrete walk-on deck FIRES-T3 model

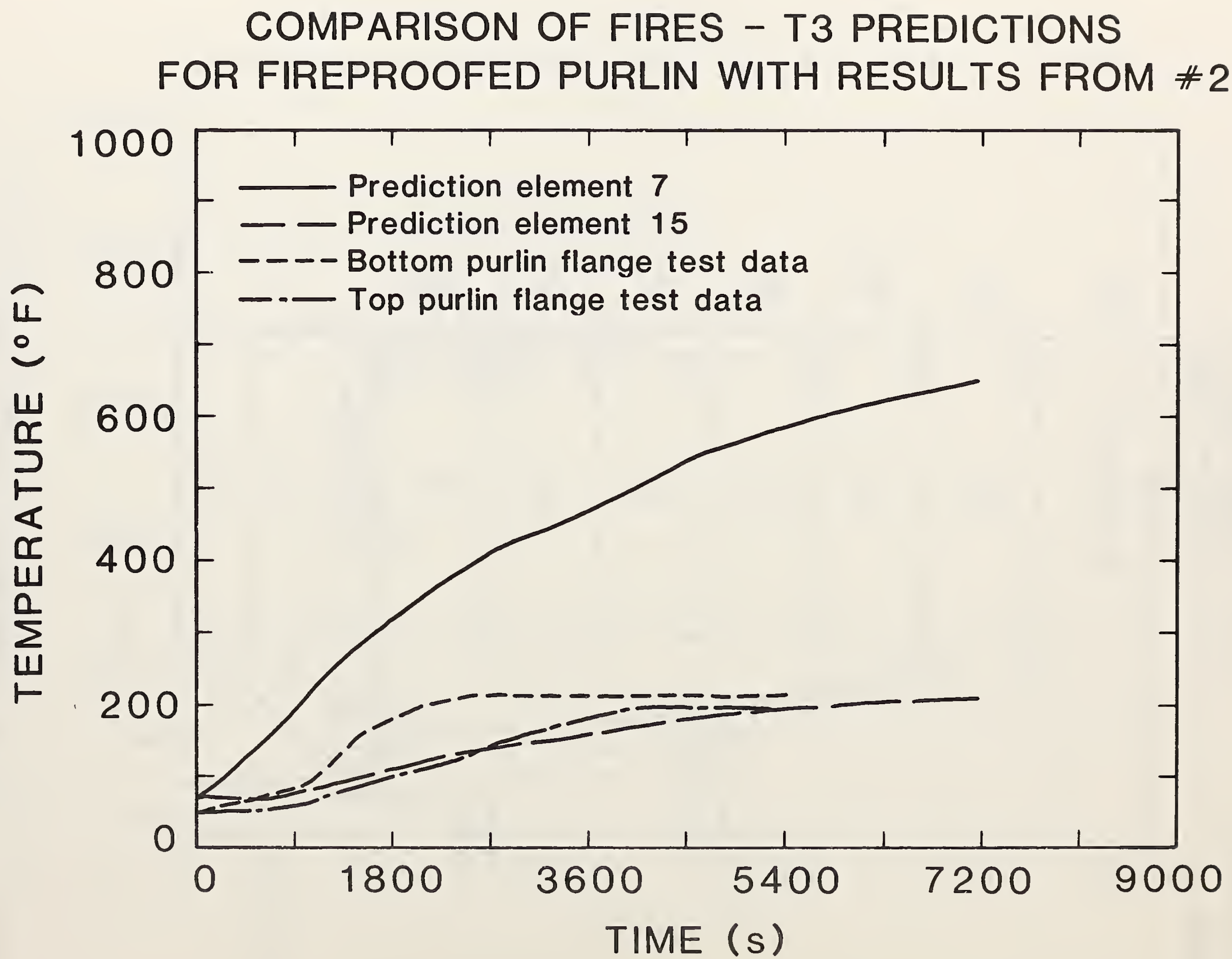


Figure 143. Comparisons of FIRES-T3 predictions for fireproofed purlin with results from test 2

Mesh for Fires – T3 Model

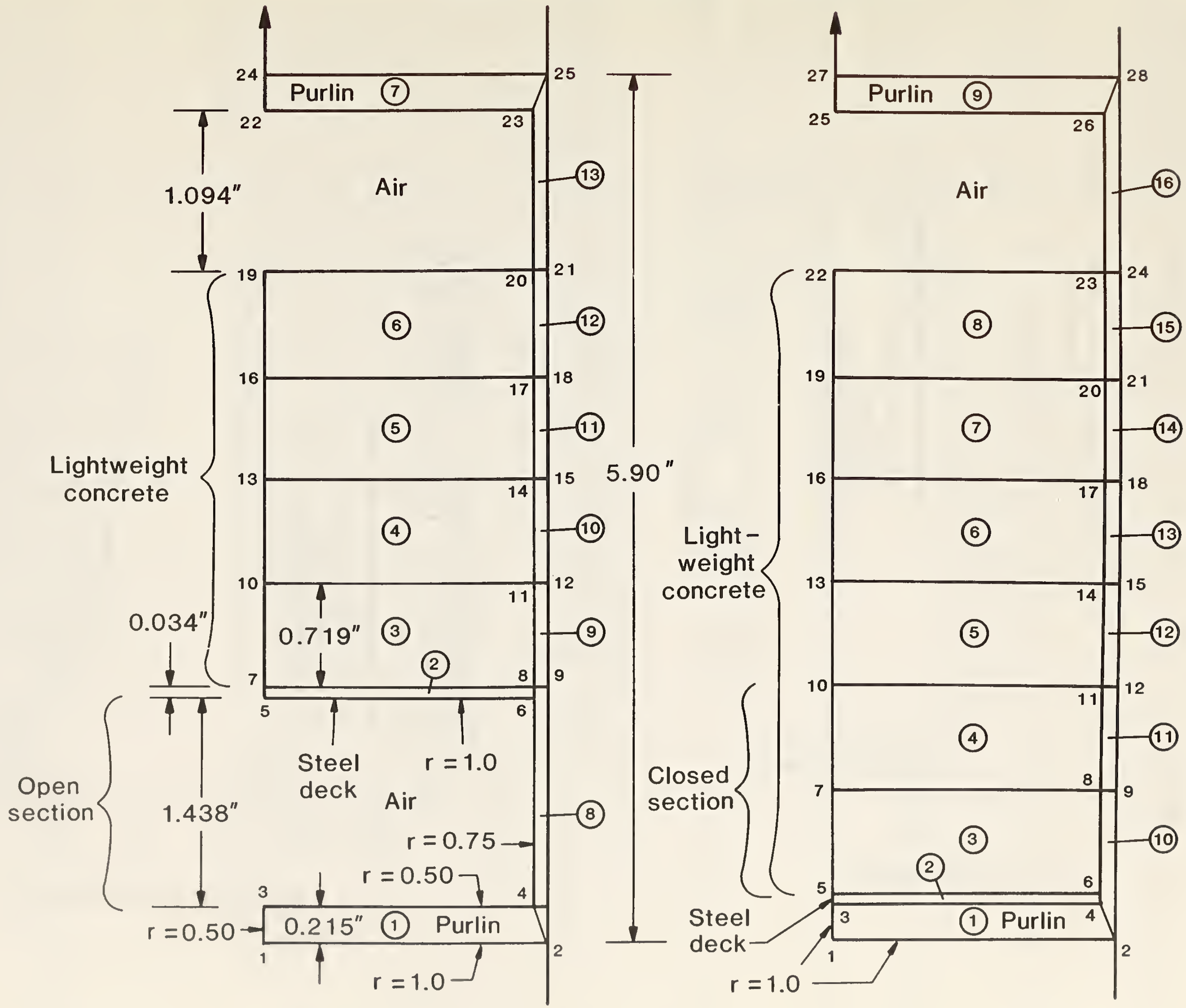


Figure 144. Node and element locations for unprotected purlins in lightweight concrete walk-on deck FIRES-T3 model

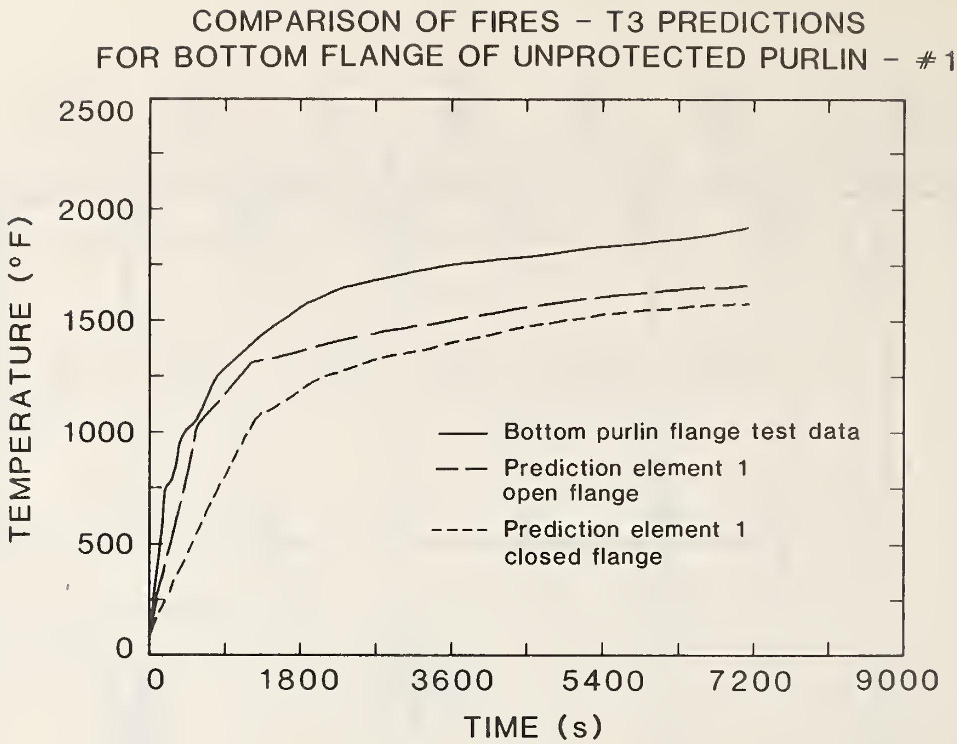


Figure 145. Comparisons of FIRES-T3 predictions for bottom flange of unprotected purlin with results from test 1

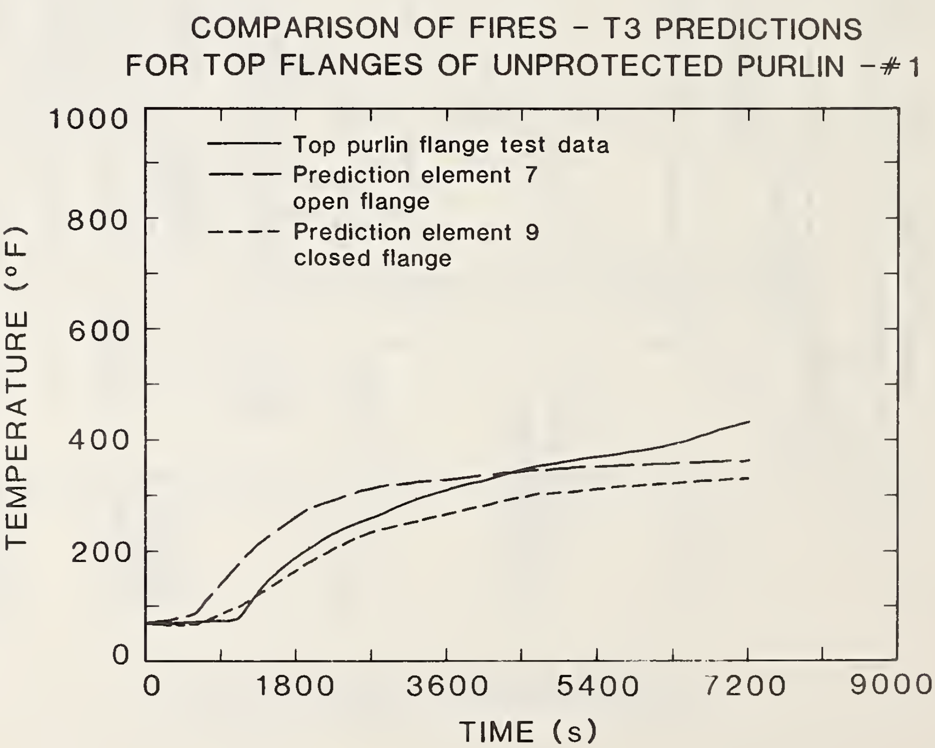


Figure 146. Comparisons of FIRES-T3 predictions for top flange of unprotected purlin with results from test 1

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

Two unique walk-on deck construction systems were exposed to the standard NFPA 251 time-temperature fire exposure in order to evaluate their fire performance. A large scale steel structure was used in the test program to simulate construction systems found in the field. The structure consisted of two large functional floors separated by an interstitial space in which a walk-on deck systems was constructed from light-weight concrete, and the second was built with poured gypsum. Three complete two hour fire tests were conducted along with one shorter test. Critical areas evaluated were the top functional floor, unprotected steel work in the interstitial space, response of the walk-on deck systems, and protection for a heavy steel column located in the center of each test bay. Test data were compared with the fire endurance test requirements of NFPA 251. Computer predictions were also made using the FIRES-T3 model to determine its ability to accurately predict the construction systems performance.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Computer models; concrete; fire endurance; fire tests; interstitial spaces; structural systems; gypsum; steel structures

13. AVAILABILITY

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