Jun 1st, 12:00 AM

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Recommended Citation

Eastman, Roderick W. and Zakrzewski, Andrew S., "The Dofasco Experimental Steel House (D.E.S.H. #1)" (1978). *International Specialty Conference on Cold-Formed Steel Structures*. 6.
https://scholarsmine.mst.edu/isccss/4iccfss/4iccfss-session4/6

THE DOFASCO EXPERIMENTAL STEEL HOUSE (D.E.S.H. #1)

by

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SUMMARY

The erection of an experimental steel house incorporating a large number of cold rolled steel products is described. Many of the light gauge steel structural components are currently under development and this house serves as a "field laboratory" in which their performance can be evaluated. Particular reference is made to results obtained, to date, from tests on the light gauge steel basement wall panels, residential steel floor joists, and load bearing "thermal" steel studs.

INTRODUCTION

Dofasco has now been involved in the development of steel components for housing for over eight years. During this period, we have developed two panelized housing systems, several panelized steel basement models, as well as framing and floor deck components.

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Some of our earlier work was reported during the two previous International Specialty Conferences on Cold-Formed Steel Structures.

In 1974, we obtained approval from our management for the construction of a Dofasco Experimental Steel House, to be located in Dofasco's Recreation Park near Hamilton, Ontario.

The detached split entry house with an attached garage was completed in the Spring of 1977.

The Experimental House was to fulfill several objectives:

(1) It would allow us to test the erection and performance of several newly developed steel components.

(2) It should prove that a rather complex house can contain an extensive amount of steel components, and yet, look like any other well designed conventionally built house.

(3) It would serve as a "field laboratory" to test the behaviour and performance of steel, as well as non-steel systems, over a long period of time, under "real life" conditions. It is hoped that the information gathered

over a period of several years will help the steel industry, and builders, to assess the merits of steel, and optimize the design of steel components.

THE USE OF STEEL

The house contains 9.5 tons (8.6 metric tons) of steel components and fitments (Figure 1). Some of them have already been commercialized, but many are of an experimental nature and will be tested and proven in the house. These include the new, improved steel basement, floor decks containing our newly developed I-shaped roll formed joists, a roll formed center beam, as well as complete steel framing for the upper walls.

Steel was also used extensively as a cladding material. Roof tiles made in the form of steel panels replaced conventional asphalt shingles. The soffit, rainware, siding and external doors were all made from steel.

THE ERECTION

One of the purposes of the Experimental Steel House was to check the erection procedures.

We wanted the challenge of a relatively complex design.

Therefore, we selected a split entry house with a raised basement, direct exit from the lower level to the back yard, and an attached garage.

(1) The Foundation

The construction began with the usual excavation, which was sized to be approximately 2' larger than the finished basement. After the installation of service connections, a 5" to 6" (12.70 cm to 15.24 cm) thick layer of 3/4" (1.9 cm) clear gravel was dumped into the excavated area, then raked and levelled. This "gravel pad" performs two functions. It becomes a water collection and draining system, and supports the basement footing.

A recent study (Appendix 1, Reference 5) indicates that the gravel pad constitutes a better drainage system than the conventional perimeter weeping tile. In our Experimental House, the water entering the gravel bed is drained to the lower sump area and pumped from there by means of a sump pump to a drainage ditch at the roadside.

The raised basement walls were backfilled 4' (1.22 m), except around the sliding door which exits into the rear yard. In order to avoid frost damage, a 4' (1.22 m) deep trench was excavated below the sliding door and filled with gravel.

A special steel channel, placed directly on the gravel, formed the perimeter house footing. In addition to galvanizing, the .107" (2.77 mm) thick section was further protected against corrosion by a .010" (.25 mm) coal tar epoxy coating. This steel footing performs several functions:

(a) It supports the whole house.

(b) It provides resistance against uplift forces.

(c) Tabs formed up in the base of the footing restrict the deflection of the bottom edge of the wall panels, which are subjected to backfill pressure (Figure 2).

(d) Openings left after forming of tabs allow any water entering the channel like footing, to drain into the gravel bed.

(e) The inside flange and lip of the footing act as a form and screed for the concrete floor.

(2) Lower Level Walls and Center Beam

The lower level walls forming the raised basement consisted of interlocking steel panels. The panels were 24" (60.96 cm) wide, 4" (10.16 cm) deep, and 8' (2.44 m) high. They were made from .036" (.91 mm), G-90 galvanized steel and were coated for additional protection and appearance above ground with an 8 mil (.20 mm) thick plastisol paint.

The panel ribs were louvered to reduce the heat flow through the walls (Figure 2), and were provided with service holes for electrical wiring. A male-female sealing groove was formed along the whole length of the panel rib, in order to prevent water penetration into the wall.

During the erection, the wall panels were placed into the footing channel and attached to it by means of nuts and bolts. Every six panels erected were secured on top with nuts and bolts to a 12' (3.66 m) long top channel, made from .060" (1.52 mm) thick galvanized steel. At the same time, joist hangers were attached to the wall panels and the top channel. The walls were then temporarily braced (Figure 3).

The basement panels were also used for the attached garage. In this case, however, the panels were 13' (3.96 m) high reaching from the footings, located 4' (1.22 m) below grade, to the roof eave.

The joist span in a house is usually reduced by provision of either a center beam or a load bearing center wall. Both systems were used in our Experimental Steel House.

The center beam was supported on conventional teleposts which were placed on 1/4" (6.35 mm) thick steel footing plates, resting directly on the gravel bed. The center beam consisted of two cold rolled steel C-sections, 8-1/2" (21.59 cm) deep, and .105" (2.67 mm) thick. Placing each 26' (7.93 m) long C-section separately on teleposts made lifting easy. The C-sections were placed back to back, and bolted to the teleposts and to each other (Figure 4).

The load bearing center wall was framed in the flat from 3-1/2" (8.89 cm) deep steel studs 24" (60.96 cm) on center, and from channel shaped top and bottom plates. All of the above components were made from .036" (.91 mm) thick G-90 galvanized steel.

After assembly, the wall frame was raised and placed on top of a 6" (15.24 cm) wide, 1/4" (6.35 mm) thick steel footing plate.

(3) Upper Level

The steel framing for the upper floor walls was assembled in 12' (3.66 m) long sections, in the flat, on the main floor deck. The frames were then sheathed on one side with 3/8" (9.5 mm) plywood, raised and braced in position (Figure 5). The framing elements consisted of 1-1/2" x 3-1/2" x .036" (3.81 cm x 8.89 cm x .91 mm) lipped "C" studs, and top and bottom channels. Two rows of slots, prepunched in the stud webs (Figure 1), reduce their thermal conductivity. Prepunched tabs, provided in the top and bottom channels at 24" (60.96 cm) intervals, assisted in speeding up the assembly of studs. They positively located and held the studs, so that no fasteners were required until the sheathing was attached to the frame.

One inch diameter holes with a curled back edge were provided in studs for electrical wiring.

Brackets, factory attached to the top plate, were provided for location and securing of roof trusses. The brackets facilitated placing of roof trusses and ensured that the trusses were located directly above the load bearing studs.

Steel was also used as a roof sheathing material. We selected panels formed from .020" (.51 mm) thick steel into the shape of tiles. The roof trusses were covered with a single layer of building paper and strapped on 16" (40.64 cm) centers, with 2" x 2" (5.08 cm x 5.08 cm) wood purlins, to which the steel tiles were nailed. In this system, the conventional plywood sheathing was eliminated (Figure 6).

The roof tiles were galvanized and covered with a natural coloured stone aggregate, embedded in an asphaltic coating. This kind of steel tile has been used extensively in several countries, but is quite new in Canada. Its appearance compares with that of expensive clay tiles.

(4) Interior and Exterior Finishes

The interior non-load bearing walls were framed using the typical non-load bearing steel studs, 16" (40.64 cm) on center. R-12 (RSI 2.1) fiberglas friction batts were used to insulate both the lower and upper floor walls. The attic was insulated with R-20 (RSI 3.5) fiberglas batts.

Half inch (1.27 cm) drywall was attached with self drilling screws to all the wall studs, and the steel joists, where a finished ceiling was required in the basement.

On the outside, the exposed front portion of the basement was clad with brick panels, consisting of 1/2" (1.27 cm) thick bricks, laminated to 1/2" (1.27 cm) thick asphalt board. The boards were attached to the steel basement panels with self drilling screws and the seams between the bricks were then grouted to look like masonry.

The upper floor walls were externally sheathed with commercially available steel siding. Steel soffit and steel rainware completed the exterior of the house (Figure 7).

THE TEST PROGRAM

The materials and components used in the house structure have to satisfy a vast range of conditions. They must withstand complex and variable loading conditions, such as soil pressure, wind loads, vertical loads including snow load, dynamic loads caused by human beings, equipment, etc. The outer envelope of the house may be subjected to external water penetration, and condensation caused by the migrating water vapour.

The components must withstand considerable temperature variations, satisfy stringent heat transfer limitations, must not warp or deflect excessively, or deteriorate in any appreciable way over a period of 50 or even 100 years. They must satisfy the human comfort conditions which encompass limitations on vibrations, transfer of sound, temperature and humidity variations, etc.

The use of steel, particularly light gauge sheet steel, has, so far, been very limited in housing applications. Consequently, the knowledge of its performance under the complex conditions is also very limited.

The main purpose of the Dofasco Experimental Steel House is to learn more about the behaviour of various steel components under "real life" conditions. To do this, various types of transducers were attached to steel components during the erection. Lead wires were run inside walls and floor cavities to a single monitoring station in the utility room, located in the basement. From this station, most of the routine measurements can be taken and instrumentation maintenance performed with little inconvenience to the occupants (Figure 8).

The tests were not restricted to measuring the behaviour of steel components only. They include the behaviour of systems affecting the steel components, such as the gravel bed, or the backfill soil, etc.

(1) Drainage

The steel footings supporting the basement walls were placed on top of a layer of gravel. While this gravel bed appears to be an excellent means of gathering and draining ground water, we also provided a conventional plastic weeping tile, placed adjacent to the footing. The gravel bed and weeping tile were drained to separate sump boxes, each of which was equipped with a sump pump and a flow meter. By using a valve, the flow from the weeping tile can be shut off. This enables us to compare the effectiveness of the two drainage systems.

During backfilling, a layer of sand was placed on top of the gravel, outside of the foundation, along one side of the house. If, after some years of service, this area was excavated and the amount of sand in the gravel determined, some assessment could be made of the degree of penetration (danger of clogging).

In order to obtain more information about the soil, the variations in the water level in the ground and gravel must be known. To do this, we placed one piezometer under the house and another in the ground close to the house.

All the above tests, while seemingly unrelated to steel, are of importance in the assessment of the "dry system" of footings, i.e. a system not using cement poured on-site.

(2) Soil Pressure

The lateral pressure exerted by the soil against the basement walls depends upon the type of soil, methods of backfilling, and the amount of moisture in the soil. The amount and distribution of pressure greatly affect the design of steel basement walls.

To monitor these conditions, we installed several earth pressure cells, placed against the outside of the basement panels at the footing level. The pressure cells will provide us with information on how the pressure changes with seasons, and how it is affected by the settlement and consolidation of the backfill material.

(3) Foundation Wall

(a) Movement

Since the steel basement panels are considerably lighter and much more flexible than concrete walls, the soil pressure will displace the basement panels to a larger degree. This displacement is being periodically determined by measuring the distance from twelve points on one section of the basement wall to a stationary reference point.

(b) Stresses

To determine load levels, changes in loads, and to uncover possible highly loaded areas, strain gauges were attached to various structural steel components throughout the house at the component's critical points. Stresses are being recorded at regular intervals.

(c) Corrosion Protection

Two different corrosion protection systems for the steel panels below ground have been installed and their performance is being monitored constantly.

(4) Heat Transfer

Thermal performance will be assessed by two methods:

(a) Infra-red photography, or "thermovision" inspection of all exterior walls is a good indication of the quality of the thermal design and insulation practices.

(b) Numerous thermocouples were attached to exterior walls at various material interfaces. These spot temperatures allow us to plot temperature profiles through the cross section of the walls. From this information the thermal performance and heat loss, both above and below ground, can be determined.

One of the major sources of heat loss is air infiltration. We have carried out an air leakage test to determine the tightness of this steel house, for comparison with that of conventional houses.

(5) Condensation

Excessive condensation inside wall or roof cavities is one of the greatest sources of trouble in houses.

We installed several humidity transducers inside the wall and roof cavities, and we expect the data obtained from them, as well as from thermocouples, will help us determine condensation potentials of steel components.

A small portion of the interior sheathing of a basement wall was made removable. This enables us to check the condition of insulation and visually check for signs of condensation and corrosion on the inside of the steel basement wall panel.

(6) Floor Deflection

Five floor deck test sections, utilizing three different types of joists, were incorporated in the upper level floor deck. The test decks were subjected to static and dynamic loads. Deflections, frequency and damping rates were determined.

(7) Acoustics

We plan to carry out acoustic tests, with the help of National Research Council personnel, in order to determine sound transmission and impact isolation coefficients.

DISCUSSION AND RESULTS

Since the house has been completed for less than one year, we will confine the discussion to areas where sufficient test data has been accumulated.

(1) Floor Joists

(a) Static Performance

The three different types of floor joists included for comparative testing were:

(i) Experimental light gauge steel I-shaped joists.

(ii) Commercially available C-shaped steel joists.

(iii) Conventional wood joists (Figure 9).

The properties of these joists are given in Table 1. The joist spacing was 24" (60.96 cm) on center, to coincide with the basement wall panel module, spanned 12' (3.66 m), and were simply supported at each end. The two types of steel joists were also used in a two span continuous application.

The 3/4" (1.9 cm) tongue and groove plywood subfloor sheathing was attached to the steel joists with adhesive and self-drilling screws. The adhesive acts as a cushion to reduce the tendency for squeaks, which can develop between the steel and wood elements. It also provides a continuous shear connection into the subfloor material. By utilizing the composite action of the floor sheathing and designing a stressed skin floor deck, longer joist spans can be achieved.

In one area of the house, the subfloor sheathing was attached to the steel joists using pneumatically driven, ring shanked T-nails. This method did prove faster than generally used self-drilling screws, and our laboratory tests have shown that when used in conjunction with adhesives, holding power equivalent to that of self-drilling screws can be easily attained.

Each deck test section consisted of three adjacent joists, with deflection measurements taken off the central joist. A special telescoping device was constructed, incorporating a dial indicator for reading the actual deflections. This device was located between the floor deck and the ceiling above.

Load was provided by successive layers of concrete blocks spread uniformly over the test area (Figure 10). The maximum loading was approximately 100 lb. per foot (140 kg/m), or 1.25 times design load (40 psf - 195 kg/sq m).

The two steel joists and the wood joists, on 12' (3.66 m) simply supported spans, produced essentially identical deflections over the load range tested. The actual deflections were only 53% of the allowable deck deflection of span (inches)/360 at design load (Figure 11).

Thus, from a static deflection standpoint, both the light gauge steel I-shaped joist and the C-shaped steel joist, 7-1/4" (18.4 cm) high, are equivalent to nominal 2" x 10" [actual dimensions 1-1/2" x 9-1/4" (3.81 cm x 23.50 cm)] wood joists, although they weigh approximately 75% and 58% less, respectively. This weight difference makes the steel joists more easily handled, particularly in long lengths. Also, since steel joists are cut to length, installation times can be significantly reduced.

Laboratory tests on similar deck sections also show that the deflection performance of these two steel joists is identical. At design load, the measured deflection was approximately 62% of allowable, and that for wood was slightly greater at 80% of allowable. The smaller deflections recorded in the actual house can be mainly attributed to the addition of adhesives and the continuity of the test sections in the transverse direction. The larger difference between laboratory and field deflections for wood is perhaps due to a better shear transfer link, via the adhesive, for wood to wood connections, as opposed to wood to steel.

The equivalency of the I and C-shaped joists was further substantiated by the two span continuous joist test results.

(b) Dynamic Performance

The same five deck test sections previously tested for static deflection have also been evaluated for comparative dynamic performance. The prime objective was to determine and compare the natural frequencies and damping rates of the various types of joists, with and without a nominal uniformly distributed load.

The natural frequencies of vibration were determined by providing a steady state, sinusoidal forcing vibration, with variable frequency, at the mid span of the central joist in the deck section. An electro-magnetic shaker was used to provide this input. The displacement probe of a vibration analyser was located next to the shaker. As the frequency was slowly increased, maximum amplitude readings were taken and plotted in Figure 12.

The fundamental natural frequencies of the two light gauge steel joists were approximately the same, i.e. 20 Hz, while that for the wood joist was approximately 18% higher (Table 3).

The human body is sensitive to frequencies and amplitudes of vibration (Appendix 1, Reference 11). The lower the frequency, the greater can be the amplitudes before the vibrations are sensed. Therefore, the lower the natural frequency of the floor system, the more acceptable it becomes.

Whether the joist spans were 12' (3.66 m) simply supported or continuous over a center support, did not affect natural frequencies significantly. However, the addition of a

10 psf (49 kg/m^2) uniform load reduced the fundamental frequencies of all joists to 14 Hz.

Damping rates for all deck test sections were calculated from the recorded response to the impact of a person dropping from the balls of his feet onto his heals (heal drop test). In most cases, rates less than 5% of critical were calculated. Thus, these floors can be considered undamped. Surprisingly, no significant difference in damping could be detected between the wood and steel joists.

The addition of the uniform load of 10 psf (49 kg/m^2) did not affect the damping rates significantly, nor did the addition of heavy carpeting with a foam underpad.

The carpet, by virtue of its cushioning properties, reduces the energy received by the floor from an impact, and the amplitude of the resulting vibration. This is often sufficient to lower the sensation to a less perceivable and, therefore, less annoying level.

(2) Foundation Walls

In Canadian housing, soil pressures are generally calculated based on a triangular pressure distribution equivalent to half hydrostatic pressure (Appendix 1, Reference 5 and Figure 13). Actual field measurements (Appendix 1, Reference 10) have shown that in certain soil conditions, pressures can be, in fact, much higher.

The soil at the site of the Experimental Steel House was hard to very stiff, silty clay with cohesive oxidized seams. The general area was low and poorly drained. These characteristics are indicative of high soil pressures. Consequently, the light gauge steel foundation wall panel was designed with a fairly high safety factor.

Because of the rigidity of conventional concrete foundations, backfilling procedures, which were developed, are somewhat crude. Little or no particular attention is paid to the placing of large, cohesive lumps or rocks. The bulldozer travels back and forth over the freshly backfilled area, compacting the surface layer. This results in high lateral pressures and a distribution considerably different to triangular.

The foundation walls of the Experimental Steel House were made from light gauge steel interlocking panels, as described earlier. The interlocking joint forms the basic structural support for both axial loads and bending loads due to backfill soil pressures. This wall has considerably lower mass and stiffness than its concrete counterpart and, therefore, the pressures exerted by the backfill soil could conceivably result in large lateral wall movement.

For the above reasons, three different parameters are being measured in order to evaluate the performance of the foundation walls. These are:

(a) Lateral displacement.

(b) Backfill soil pressure.

(c) Foundation panel stresses.

(a) <u>Lateral Displacement</u>

During construction, at the bottom of the excavation, a 6" (15.24 cm) diameter hole was augered to bedrock and filled with concrete. This formed a stationary reference point, relative to which lateral displacements of the foundation wall could be measured. Twelve locations on one section of the foundation wall were selected, and the measurements taken with a linear measuring geotechnical instrument. Lateral displacements were calculated from a vector analysis, based on the assumption of one directional movement only.

The connection between the top of the foundation wall panel and the main floor deck was somewhat flexible, and permitted some lateral movement. A maximum displacement of 1/4" (6.35 mm) was recorded near the top of the wall, as well as at mid height (Figure 14). While these displacements are greater than those encountered with concrete foundations, the resulting stresses are still relatively low.

For the twelve months since erection, the displacements have been increasing. As the soil consolidates, displacements at the top of the wall should increase less rapidly, or decrease as those nearer the bottom continue to increase.

(b) Backfill Soil Pressures

Four Terra-Technology, pneumatic earth pressure cells were installed at various locations outside the foundation wall, at the footing level. One of these was located inside the garage which was backfilled, and a 3" (7.62 cm) concrete floor poured on top.

Prior to installation, the cells were calibrated in the laboratory for variations in temperature, and also on site, to account for the flexibility of the foundation panel.

Initially, all but one of the backfill pressure measurements were in excess of the accepted design value [i.e. half hydrostatic pressure = .785 psi (.055 kg/cm^2), Table 2].

Some variations between cells were observed, depending on the extent of heavy equipment activity in the vicinity of the cell. The cell located inside the garage has recorded pressures greater than full hydrostatic, i.e. 1.57 psi (.11 kg/cm^2). The consolidation process is becoming evident by a general pressure increase from October 1976 and October 1977. As more information is received, it may also be possible to detect seasonal changes in pressure, which result from differences in moisture content of the soil.

(c) Foundation Panel Stresses

Strain gauges were installed on the foundation panel ribs at various locations around the house perimeter.

The position of the gauges coincided with the estimated points of maximum moment for bending, due to backfill soil loads, assuming a triangular pressure distribution, and half hydrostatic pressure (Figure 13).

Generally, the recorded stress levels have been 60% to 90% of the calculated levels, based on the above assumptions. At one location, stresses of twice the magnitude of the theoretical stresses were observed. There is, however, no immediate concern over this result, since a good factor of safety was incorporated into the design, and this stress is still well within the elastic limit for the material.

(3) Corrosion Protection

In order to provide long life for the steel basement below ground, the steel substrate must be protected against corrosion. In this steel basement, corrosion is being controlled in three ways:

(a) The steel is hot dip galvanized to provide corrosion protection below, as well as above ground.

(b) The galvanized surface is coated with a non-conducting organic coating to retard the corrosion of the zinc coating.

(c) Cathodic protection is being used to protect the zinc coating and the steel at areas of coating damage, or where moisture has penetrated the organic coating.

This provides a fail safe protection system. If the cathodic protection circuit should be temporarily shut off, then the organic and zinc coatings will protect the steel.

There are two methods of applying cathodic protection to a structure, either galvanic current or impressed current. Each method can be "tailored" to suit the size and shape of the structure, the environment, and the desired protection. Both systems have been installed in the Experimental Steel House and the merits of each are being evaluated.

The results to date are encouraging and we are optimistic that both systems will provide the necessary long term protection.

(4) Thermal Performance

(a) Infra-Red Investigation

Heat loss through exterior steel frame construction is not of great concern, since the amount of heat conducted through the small cross section of the web is small in proportion to the overall heat loss. Of particular concern, however, are the possibilities of dust marking and condensation.

The deposition of airborne contaminents on the inside wall surface is caused by surface temperature gradients between the stud and stud space. Dust accumulates on cooler areas of the wall faster than on adjacent warmer areas.

Condensation occurs when moisture laden air, migrating through the wall, comes in contact with a surface whose temperature is lower than, or equal to, the saturation temperature.

To reduce the possibility of either of these conditions occurring near the inside finished wall surface, in the exterior envelope of the house, alternate rows of slots have been provided in the web of all light gauge steel members. The slots were located as close to the outside flange of the stud member as possible, so that the majority of stud material will be on the warm side of the slots.

For the climatic conditions in the Hamilton area, the minimum number of rows of slots has been determined to be two. An investigation, using infra-red thermovision equipment, has revealed inside surface temperature gradients less than 5°F (2.78°C). This is only 50% of the Central Mortgage and Housing Corporation acceptance value (Appendix 1, Reference 4). Figure 15 shows surface temperature readings for typical walls on the main floor and basement levels.

It is interesting to note that although the inside air temperature in both the basement and main floor levels was the same, the framing temperatures in the basement walls were generally a few degrees higher than those in the main floor walls. Thus, the temperature gradients and dust marking potentials are less. The stabilizing and insulating effect of the soil outside the foundation wall has resulted in a more even wall temperature distribution.

(b) Thermocouple Measurements

Readings from Copper/Constantan thermocouples located throughout the structure have been used to calculate heat loss and condensation potentials. Figures 16 and 17 show typical interface temperatures for both wood and steel studs included in the same wall of the house. The temperature drop across the steel stud is 9°F (5°C) less than that across the wood stud, and because of the higher thermal conductivity of steel, its average temperature is also higher. At inside conditions of 60°F (15.5°C) and 40% relative humidity, condensation will occur at a surface temperature which is 35°F (1.7°C) or lower. Consequently, condensation should occur in the wood frame construction at the inside surface of the sheathing, before it occurs in steel frame construction (Figure 17).

According to our temperature measurements so far, the two rows of thermal slots have resulted in a maximum temperature drop of 11°F to 15°F (6.1°C to 8.3°C) across the stud.

(c) Air Leakage

It has been estimated that infiltration of cold air can account for up to 40% of the total heat loss from a house (Appendix 1, Reference 3). If this infiltration can be limited to provide the exact amount of fresh air needed to maintain a comfortable environment inside the house, a considerable saving of heating energy could be realized.

The major contributor to infiltration is the existence of cracks and gaps in the structure caused by dimensional inexactness of the materials, methods of joining, changes in moisture content, etc. The precision and exactness with which steel framing components can be manufactured and erected, and its ability to be "engineered", makes steel framing an ideal candidate for a low air leakage "energy saving" house.

A simple method for determining a leakage area, equivalent to that of cracks and openings in the outer shell of a house, has been developed by Ontario Hydro (Appendix 1, Reference 8). It consists of mounting an axial flow fan through a flexible plastic film placed over a window. The sheet is taped to the window frame forming an air tight seal. A rubber hose, installed through the plastic film, is used to provide an inclined manometer with a pressure tap to outside. After all exterior doors and windows have been closed, the exhaust fan is switched on and the static pressure drop in the house noted. This pressure reading is then converted to an equivalent leakage area (ELA) by using a calibration chart.

While the fan is operating, an observer searches for openings in the structure that allow entry of cold air from outside. During cold weather, outside air being driven into the house can be detected by feel, revealing sources of air leakage that would otherwise not be observed.

To determine a figure of merit of leakage independent of house size (leakage coefficient, LC), the leakage area is divided by the house volume.

The typical range of equivalent leakage area (ELA) in single family houses is between 0.7 and 3.0 square feet (650 and 2,790 square cm). The ELA measured at the Experimental Steel House was 1.9 square feet (1,765 square cm). This value is quite acceptable, particularly in view of the fact that the furnace chimney and fireplace combustion intake were undampered, and had a combined leakage area of 0.5 square feet (465 square cm).

The areas around electrical service, plumbing entrances into the house, fireplace and exhaust fan dampers are common entries for infiltrating air. In the

Experimental House, these areas were evaluated as good to above average. However, the front door and attic access cover were observed to have a poor fit and the side door into the garage had no weather stripping. These are sources of high infiltration, which can easily be eliminated before the next heating season.

Typical values for leakage coefficient (LC) range between 0.6 and 1.5. Houses having coefficients greater than 1.10 are not very tightly constructed and probably have cold areas and high heating energy consumption. Houses having leakage coefficients less than 0.85 indicate tight construction and probably suffer from associated problems of high indoor humidity, wall staining and lingering household odours. The leakage coefficient for the Experimental Steel House was 0.96, exactly mid point in the range of coefficients for "problem free" houses (i.e. between 0.85 and 1.1).

In comparison with information available from Ontario Hydro, the Experimental Steel House appears to be slightly better built (tighter) than frame houses of traditional materials and construction (i.e. LC = 0.96 compared to LC = 0.99).

CONCLUSIONS

(1) A house which extensively utilizes steel components can be as attractive as any conventionally built house.

(2) The dimensional exactness of steel makes it ideally suited for preengineered and simplified construction. Even a relatively complex house design can be erected quickly and easily.

(3) The weight of light gauge steel structural components is generally considerably lower than that of equivalent traditional components.

(4) Light gauge steel foundation wall panels can be designed to withstand relatively high soil pressures. Deflections and stresses can be kept within acceptable limits.

(5) The thermal performance of properly designed steel components can be made equal to, or often better than, that of conventional construction materials.

(6) Steel structural members can be designed to avoid excessive condensation. The point of condensation in the steel stud wall was closer to the exterior skin of the house, and therefore, better than the wood stud wall.

(7) Under these test conditions, the static and dynamic characteristics of light gauge steel residential floor joists are every bit as good as wood joists.

(8) When using steel components, a "tight" house can be built, which is very desirable from an energy conservation point of view.

APPENDIX 1 - REFERENCES

(1) "ASHRAE Handbook of Fundamentals", American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, New York, 1972.

(2) "Design Criteria for Basement Foundation Systems in Canadian Housing", The Technical Research Committee, Housing and Urban Development Association of Canada, Toronto, Canada, 1975.

(3) "Energy Saving Homes - The Arkansa Story", Report No. 1, Owens Corning Fiberglas, Toledo, Ohio, June 1976.

(4) "Exterior Wall Steel Stud Systems", Acceptance Bulletin, Central Mortgage and Housing Corporation, Ottawa, Canada.

(5) "Field Performance of Gravel Pad Drainage Installations Under Basements", The Technical Research Committee, Housing and Urban Development Association of Canada, Toronto, Canada.

(6) Latta J. K., "Walls, Windows and Roofs for the Canadian Climate", Special Technical Publication No. 1, Division of Building Research, National Research Council of Canada, Ottawa, Canada, 1973.

(7) Lenzen K. H., "Vibration of Steel Joist Concrete Floor Slabs", AISC Engineering Journal, July 1966.

(8) "Research Quarterly", Ontario Hydro, Volume 26 Number 4, Fourth Quarter, 1974.

(9) "Residential Standard 1975", Associate Committee on the National Building Code, National Research Council of Canada, Ottawa, Canada.

(10) Tao S. S. and Hamilton J. J., "Performance of the Mark IX Steel Basement to 31 January 1975", Division of Building Research, National Research Council of Canada, Ottawa, Canada, Technical Note No. 595, November 1975.

(11) Wiss John F. and Parmelee R. A., "Human Perception of Transient Vibrations", Journal of the Structural Division, ASCE, Volume 100 Number ST4, April 1974.

TABLE 1 - PROPERTIES OF TEST JOISTS

	"I" SHAPE STEEL	"C" SHAPE STEEL	WOOD
OVERALL DIMENSION IN. (CM)	1.7 x 7.375 (4.32 x 18.73)	1.525 x 7.25 (3.87 x 18.4)	1-1/2 x 9-1/4 (3.8 x 23.5)
MATERIAL THICKNESS IN. (MM)	CHORD .039 (.99) WEB .025 (.64)	.061 (1.55)	1-1/2 (38)
WEIGHT PER FOOT LB./FT. (KG/M)	1.803 (2.68)	2.337 (3.49)	3.18 (4.73)
MOMENT OF INERTIA $IN.^4$ (CM^4)	4.453 (185.3)	4.619 (192.3)	98.932 (4117.9)
STIFFNESS EIx $LB.IN.^2 \times 10^6$ $(KG\ M^2 \times 10^4)$	133.59 (3.909)	138.57 (4.055)	118.72 (3.474)
CROSS SECTIONAL AREA $IN.^2$ (CM^2)	.500 (3.23)	.660 (4.26)	13.875 (89.52)

TABLE 2 - LATERAL EARTH PRESSURE MEASUREMENTS (PSI) (KG/CM^2)

CELL No.	OCT. 26/76	DEC. 9/76	APRIL 12/77	MAY 26/77	JUNE 28/77	AUG. 15/77	OCT. 6/77
837	.47 (.033)	.54 (.038)	.95 (.067)	.85 (.060)	.5 (.035)	.3 (.021)	.64 (.045)
838	1.36 (.096)	1.5 (.105)	1.67 (.117)	1.77 (.124)	1.75 (.123)	1.67 (.117)	1.75 (.123)
839	.79 (.056)	.52 (.037)	1.48 (.104)	1.4 (.098)	1.75 (.123)	1.54 (.108)	1.39 (.098)
840	11.18 (.083)	1.62 (.115)	1.14 (.150)	2.34 (.164)	2.22 (.156)	1.97 (.138)	2.17 (.152)

TABLE 3 - VIBRATION TEST DATA

JOIST TYPE	TEST CONDITIONS	% CRITICAL DAMPING FILTERED ± 10% BAND WIDTH	NATURAL FREQUENCY C.P.M. (Hz)
DOFASCO SOLID WEB	BARE FLOOR (B.F.) NO LOAD (N/L)	5.1	1,200 (20)
24' (7.32 M) CONTINUOUS	BARE FLOOR (B.F.) 10 PSF LOAD (L) (48.8 KG/M^2)	5.36	825 (13.75)
12' (3.66 M) SPAN	CARPTED (C) NO LOAD (N/L)	3.77	1,250 (20.8)
DOFASCO SOLID WEB	B.F. N/L	4.51	1,200 (20)
12' (3.66 M) SIMPLY SUPPORTED	B.F. L	4.92	810 (13.5)
12' (3.66 M) SPAN	C N/L	4.41	1,200 (20)
"C" SHAPE	B.F. N/L	4.1	1,275 (21.25)
24' (7.32 M) CONTINUOUS	B.F. L	4.67	825 (13.75)
12' (3.66 M) SPAN	C N/L	4.37	1,250 (20.83)
"C" SHAPE	B.F. N/L	4.08	1,225 (20.42)
12' (3.66 M) SIMPLY SUPPORTED	B.F. L	4.66	825 (13.75)
12' (3.66 M) SPAN	C N/L	4.77	1,350 (22.5)
WOOD 2" x 10" (5.1 CM x 25.4 CM)	B.F. N/L	4.3	1,475 (24.50)
12' (3.66 M) SIMPLY SUPPORTED	B.F. L	4.92	825 (13.75)
12' (3.66 M) SPAN	C N/L	4.47	1,500 (25)

Figure 1

FLAT-ROLLED STEEL IN THE DOFASCO EXPERIMENTAL STEEL HOUSE

COMPONENTS	TOTAL	WT. in LBS.
A. HOUSE FRAMING COMPONENTS		
1- STUDS	540·1	
2- CORNER STUDS	30·0	
3- TOP & BOTTOM CHANNELS	247·2	
4- JOISTS	1138·4	
5- JOIST HANGERS	19·6	
6- SILLS-LINTELS-INFILL	130·5	
7- LINTEL BEAM	321·5	
8- TRUSS BRACKET	90·0	
BASEMENT WALL COMPONENTS		
9- WALL PANELS		
a)- House-- 8'-8" high --	3215·3	
b)- Garage-12-10 high --	2187·9	
10- PANEL STIFFENERS		
a)- House--------------------	173·2	
b)- Garage-------------------	79·6	
11- CORNER STUDS	261·0	
12- SILLS-LINTELS-INFILL	148·0	
13- LINTEL BEAMS	286·0	
14- JAMB REINFORCEMENTS	340·0	
15- TOP CHANNEL		
a)-House	246·6	
b)-Garage	113·3	
16- FOOTING PLATE		
a)-House	553·7	
b)-Garage	254·4	
MAIN FLOOR CENTER SUPPORT		
17- CENTER BEAM	280·8	
18- JACK TELEPOST	90·0	
19- INTERNAL PARTITION STUD	1183·5	
20- INTERNAL PARTITION CHANNELS	143·1	
SUB-TOTAL		12073·7

COMPONENTS	TOTAL	WT. in LBS.
B. OUTER ENCLOSURE		
1- ROOFING	2198·6	
2- SOFFIT and FASCIA	278·4	
3- STEEL SIDING	796·5	
4- EXTERIOR STEEL DOOR	300·0	
5- GARAGE DOOR	110·0	
SUB-TOTAL		3683.5
C. SEPTIC TANK — SUB-TOTAL		1000·0
D. OTHER COMPONENTS		
1- RAINWARE	116·0	
2- DUCT WORK	300·0	
3- FURNACE ENCLOSURE	100·0	
4- FIREPLACE	200·0	
5- INTERIOR DOOR FRAMES	216·0	
6- BI-FOLD CLOSET DOORS	80·0	
7- CLOSET SHELVES	37·0	
8- KITCHEN VANITIES and CABINETS	1152·0	
SUB-TOTAL		2201·0

TOTAL LBS. 18,958·2

TOTAL TONS. 9·48

THE D.E.S.H.-#1 EXPERIMENTAL HOUSE IS A SPLIT LEVEL ENTRY HOUSE
24'x50' WITH A 12'x22' ATTACHED GARAGE

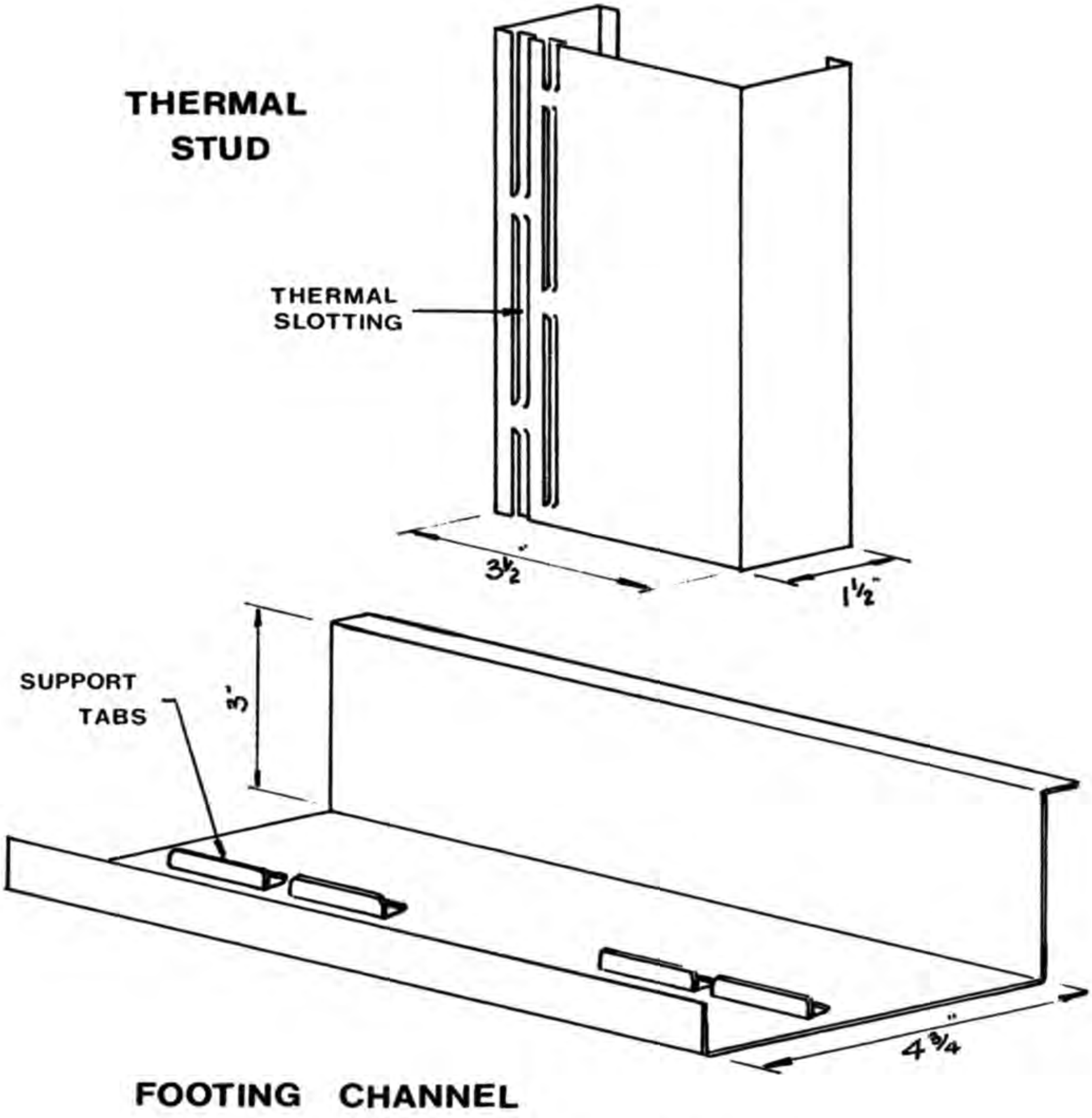


Figure 2 - Stud and Footing Channel Details

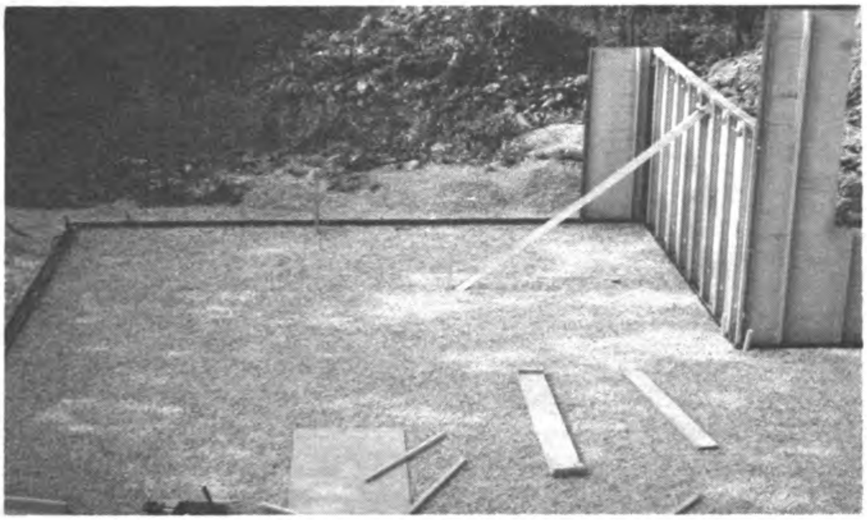


Figure 3 - Gravel Bed, Footing Channel and Basement Panels

Figure 4 - Lifting the Two Piece Center Beam into Position

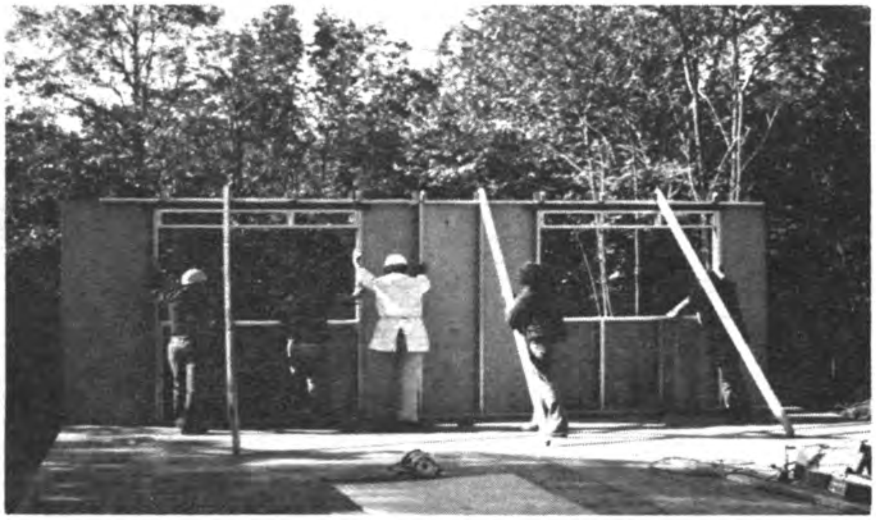


Figure 5 - Raising the Upper Wall into Position

Figure 6 - Installing the Light Gauge Steel Roof Tiles

Figure 7 - The Finished House

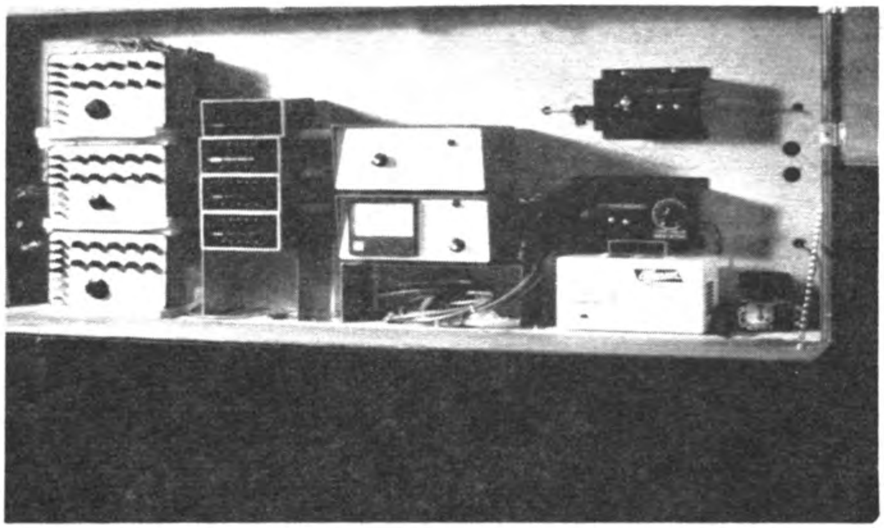


Figure 8 - Instrumentation Cabinet

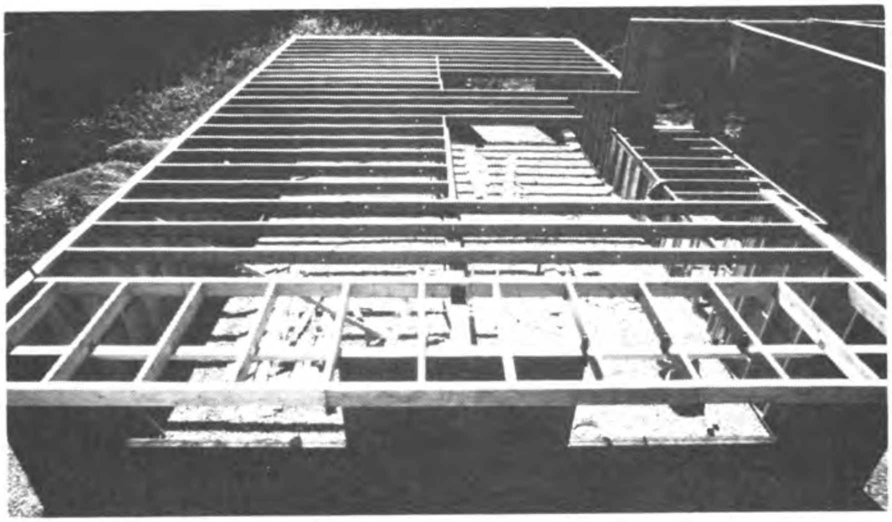


Figure 9 - Joist Framing

Figure 10 - Concrete Blocks Used in Static Deflection Test

Figure 11

DEFLECTION DATA FOR 12 Ft. FLOOR DECKS

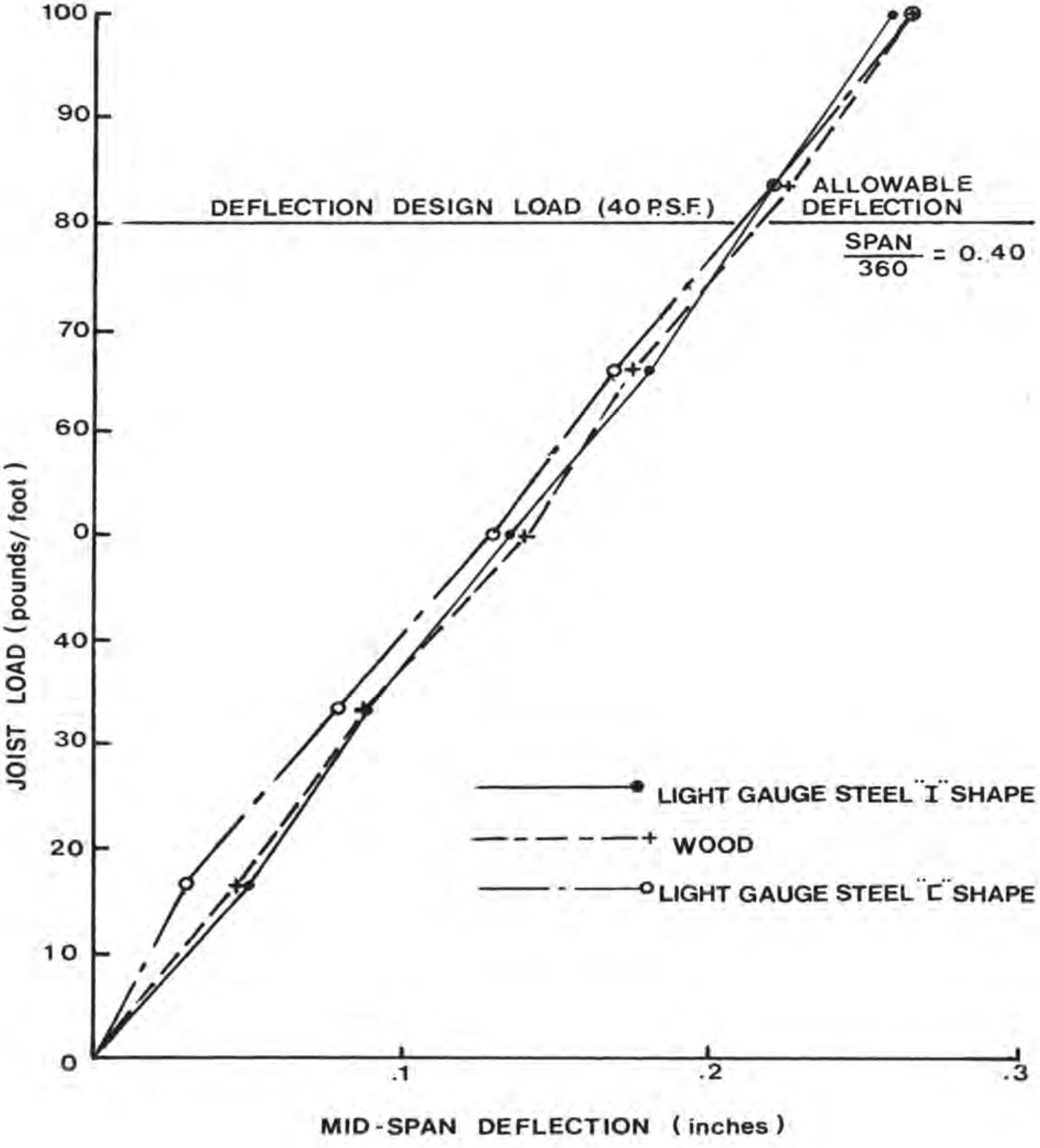


Figure 12

LIGHT GAUGE STEEL "I" SHAPED JOIST DECK

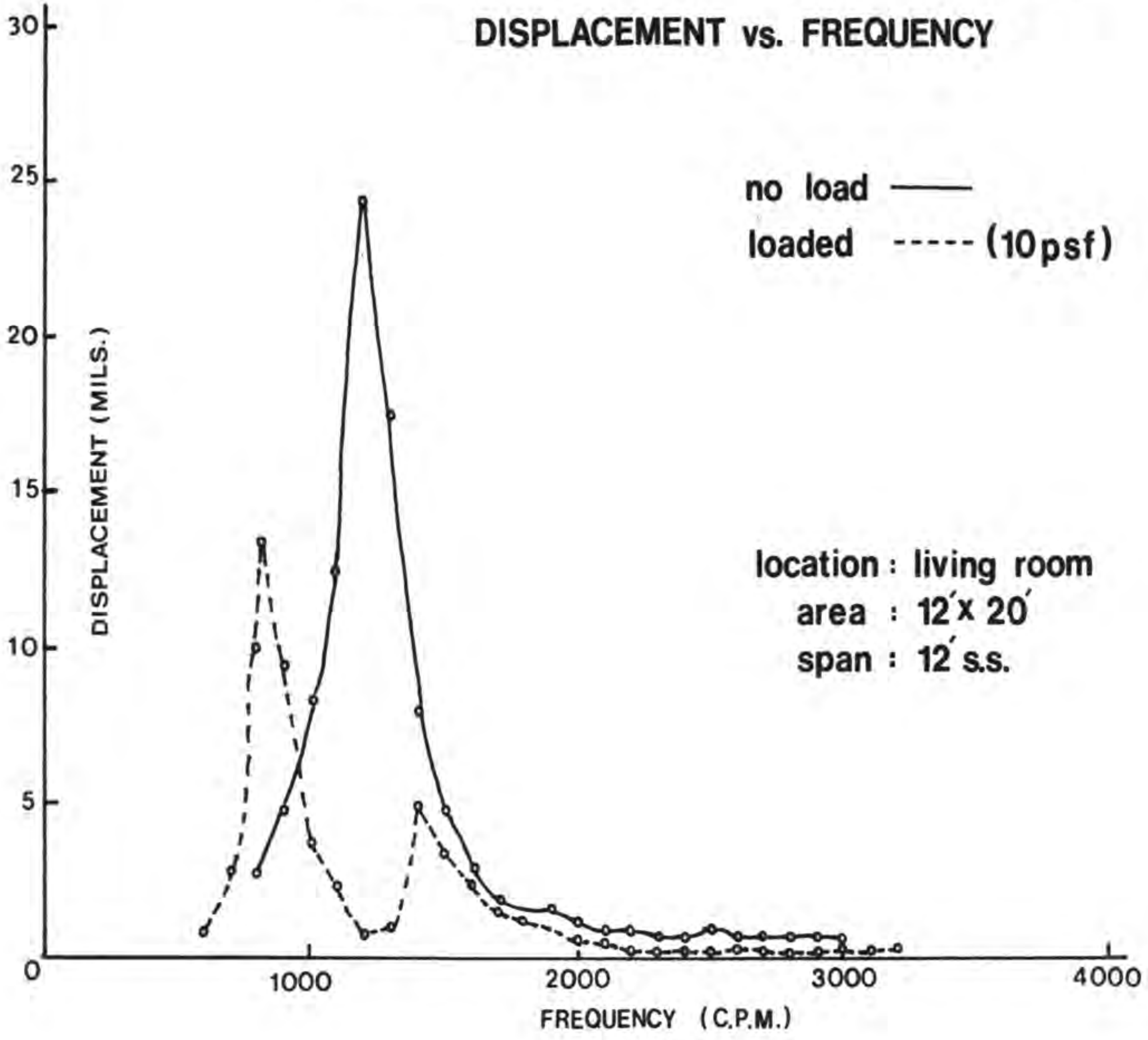
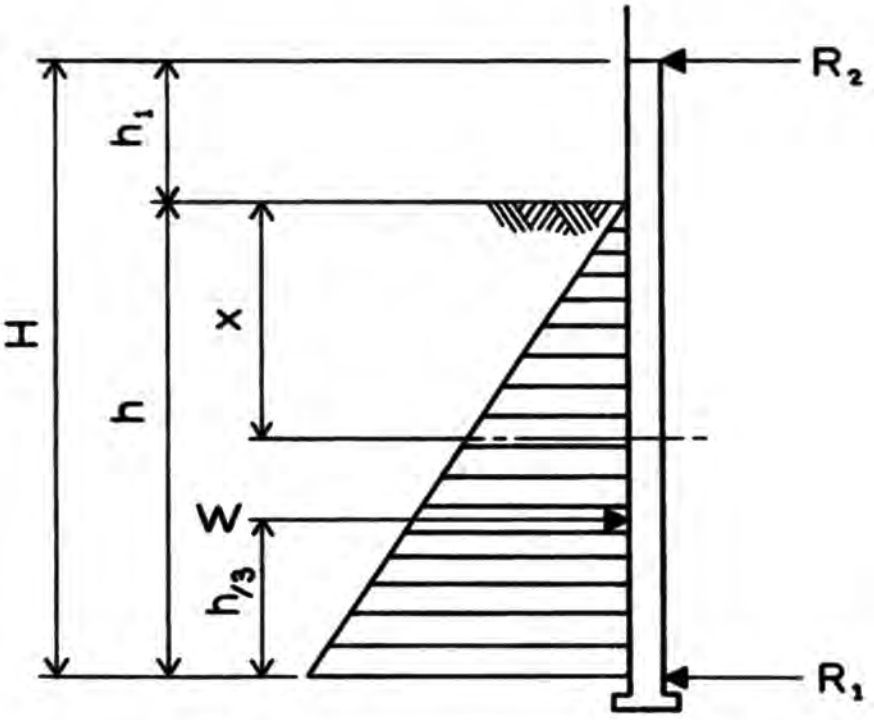


Figure 13

SOIL PRESSURE DIAGRAM



w - LATERAL SOIL PRESSURE, EQUIVALENT FLUID 30 PCF

W - TOTAL LATERAL LOAD = $\frac{wh^2}{2}$

h = DEPTH OF BACKFILL

H = HEIGHT OF WALL

R_1 = MAXIMUM SHEAR = $W - \frac{Wh}{3H}$

x = POINT OF MAXIMUM MOMENT = $h\sqrt{\frac{h}{3H}}$

M = MAXIMUM MOMENT = $\frac{Wh}{3H}\left[h_1 + \frac{2h}{3}\sqrt{\frac{h}{3H}}\right]$

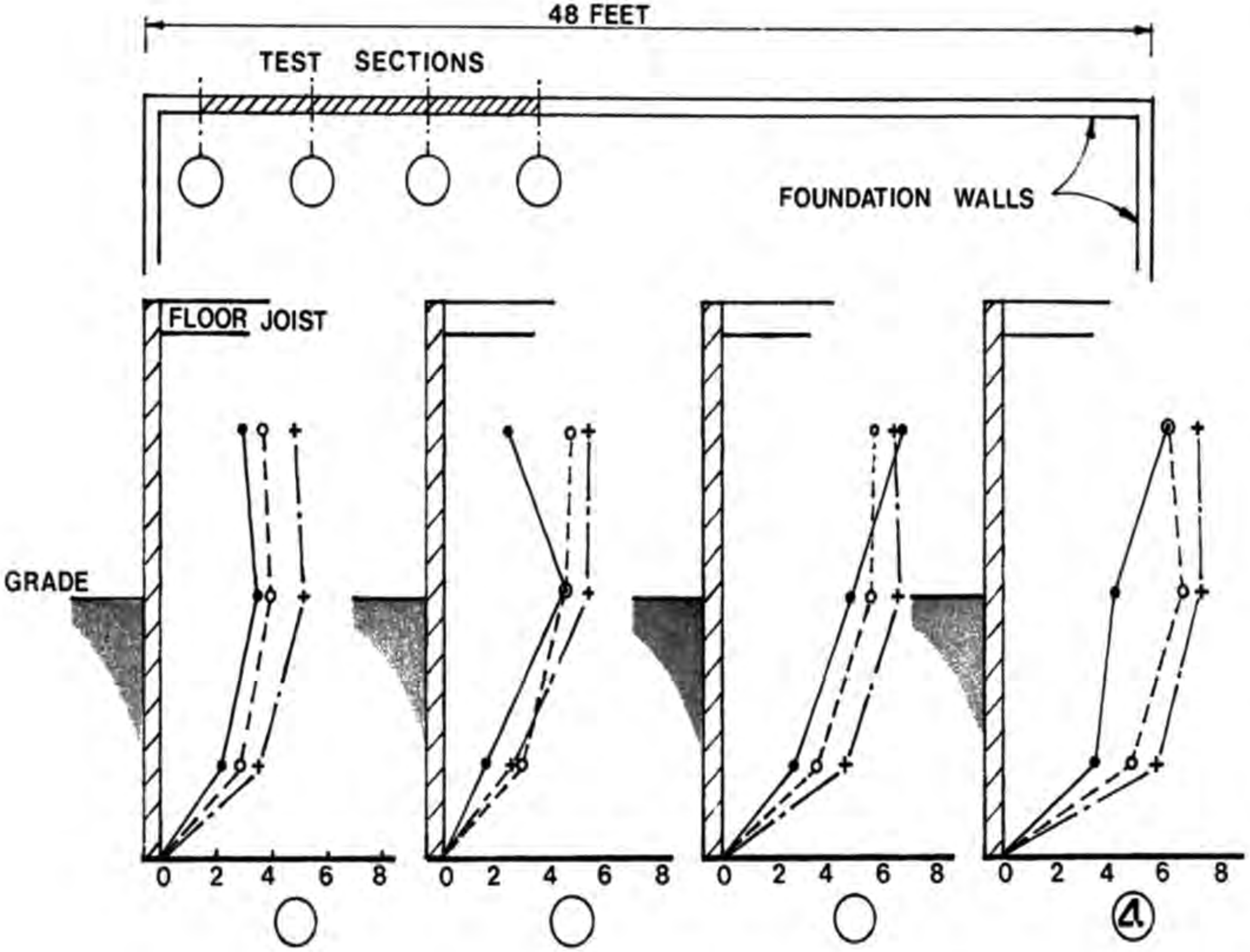
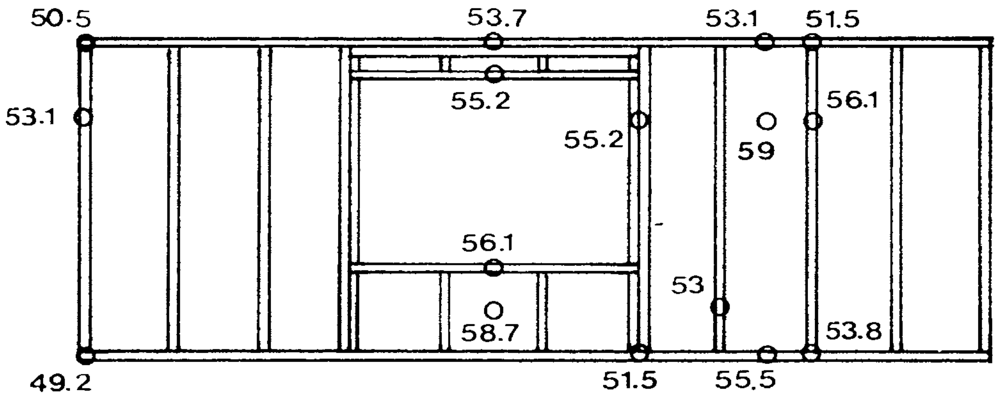
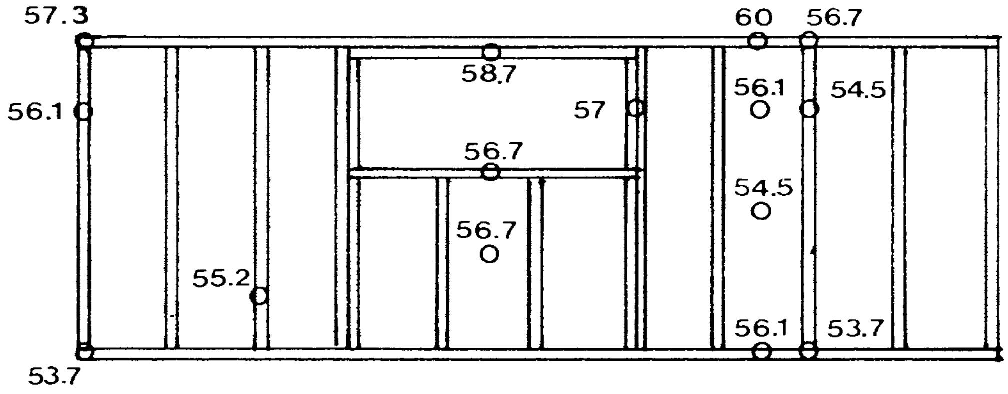


Figure 14 **LATERAL DISPLACEMENT** (mm.)



INSIDE AIR 60° F
OUTSIDE AIR 12° F

UPPER LEVEL



INSIDE AIR 60° F
OUTSIDE AIR 12° F

BASEMENT LEVEL

Figure 15

— TYPICAL INSIDE SURFACE TEMPERATURES —

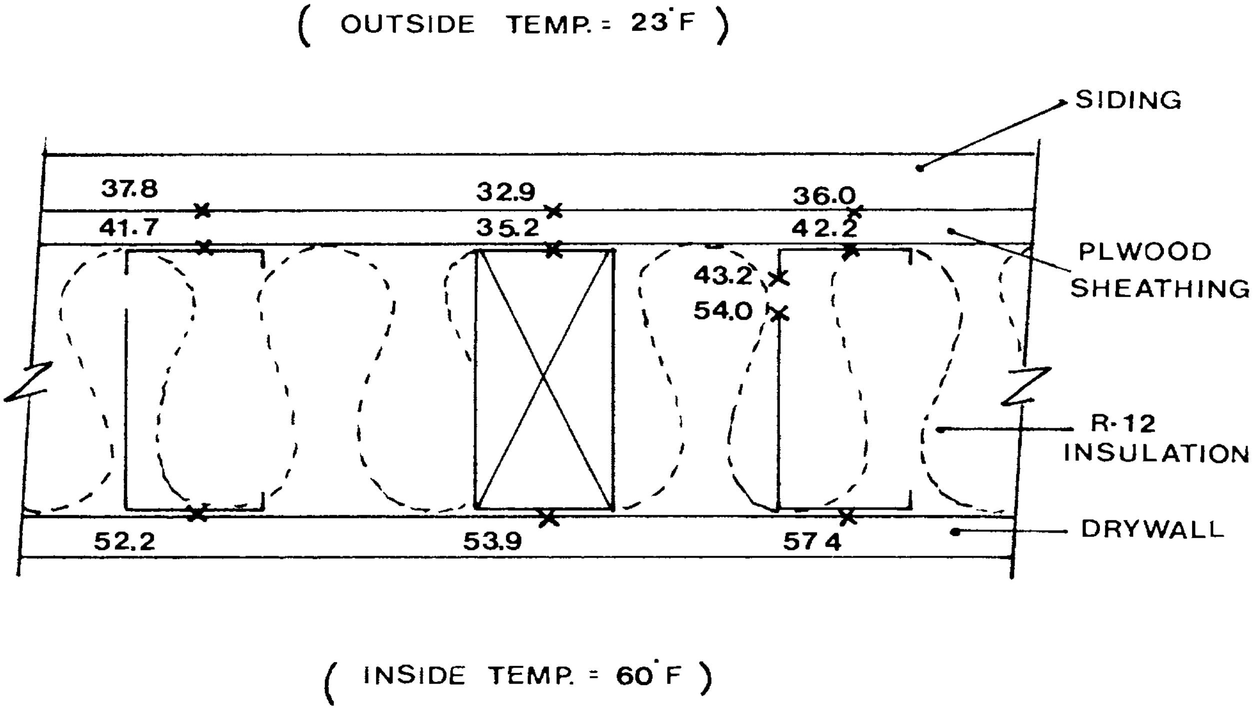
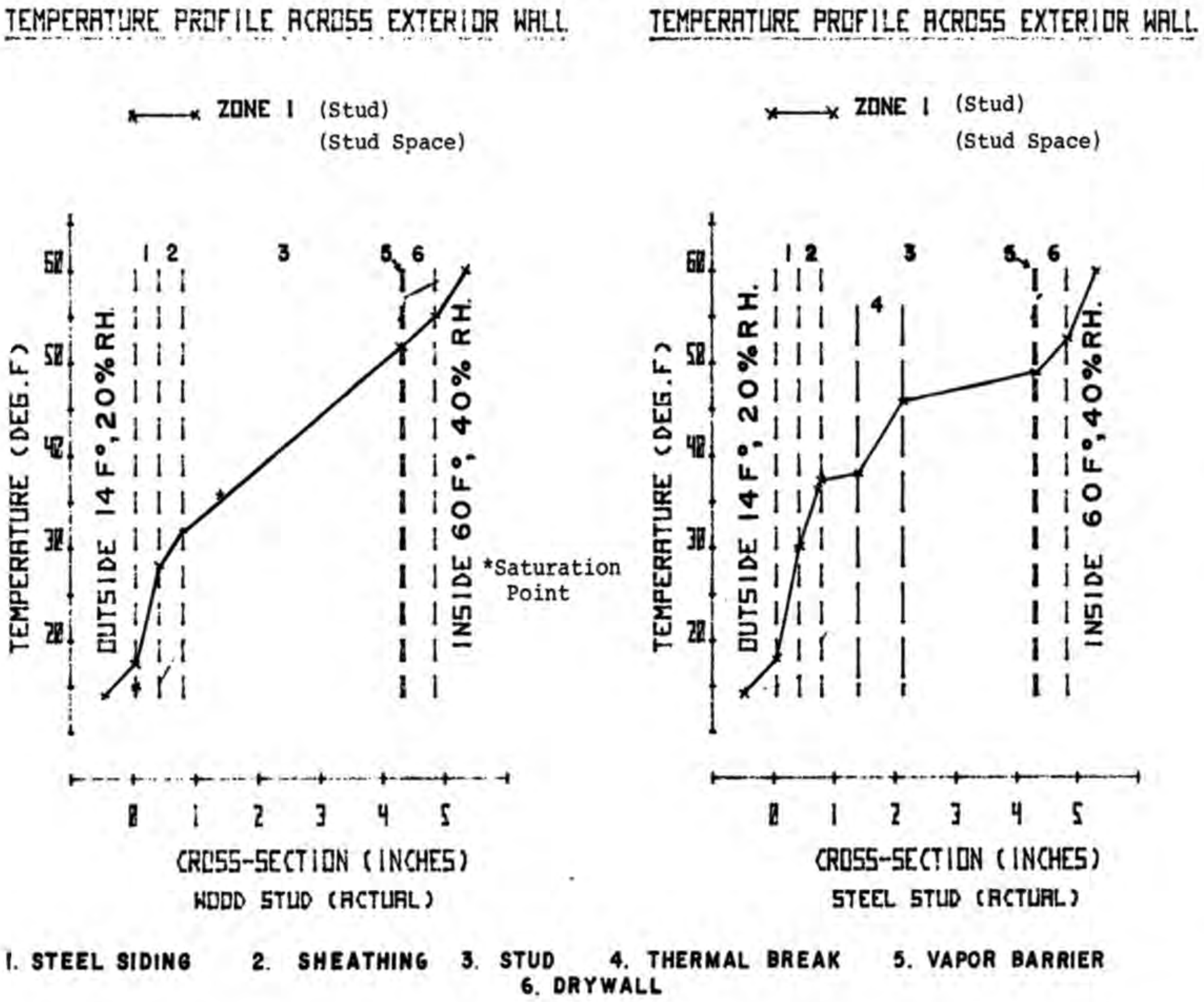


Figure 16

INTERFACE TEMPERATURES - MAIN WALL FRAME

Figure 17


TEMPERATURE PROFILE ACROSS EXTERIOR WALL
ZONE I (Stud)
(Stud Space)
TEMPERATURE (DEG.F)
50
50
40
30
20
OUTSIDE 14 F°, 20% RH.
INSIDE 60 F°, 40% RH.
1 2 3 5 6
*Saturation Point
0 1 2 3 4 5
CROSS-SECTION (INCHES)
WOOD STUD (ACTUAL)
TEMPERATURE PROFILE ACROSS EXTERIOR WALL
ZONE I (Stud)
(Stud Space)
TEMPERATURE (DEG.F)
60
50
40
30
20
OUTSIDE 14 F°, 20% RH.
INSIDE 60 F°, 40% RH.
1 2 3 4 5 6
0 1 2 3 4 5
CROSS-SECTION (INCHES)
STEEL STUD (ACTUAL)
1. STEEL SIDING
2. SHEATHING
3. STUD
4. THERMAL BREAK
5. VAPOR BARRIER
6. DRYWALL