RESEARCH REPORT

Results of Fire-Resistance Tests on Small-Scale Insulated and Non-insulated Gypsum Board Protected Wall Assemblies

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RESULTS OF FIRE RESISTANCE TESTS ON SMALL-SCALE, INSULATED AND NON-INSULATED, GYPSUM BOARD PROTECTED WALL ASSEMBLIES

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RÉSULTATS D'ESSAIS DE RÉSISTANCE AU FEU MENÉS SUR DES ASSEMBLAGES MURAUX À PETITE ÉCHELLE, ISOLÉS ET NON ISOLÉS, PROTÉGÉS PAR DES PLAQUES DE PLÂTRE

par

M.A. Sultan et G.D. Lougheed

RÉSUMÉ

Ce rapport présente les résultats de 48 essais de résistance au feu menés au Laboratoire national de l'incendie sur des assemblages muraux à petite échelle, isolés et non isolés, protégés par des plaques de plâtre. Quatre assemblages muraux ont été étudiés : installation symétrique 1 sur 1 (une plaque de plâtre sur la surface exposée et sur la surface non exposée); installation asymétrique 1 sur 2 (une plaque de plâtre sur la surface exposée et deux plaques de plâtre sur la surface non exposée); installation asymétrique 2 sur 1 (deux plaques de plâtre sur la surface exposée et une plaque de plâtre sur la surface non exposée); installation symétrique 2 sur 2 (deux plaques de plâtre sur la surface exposée et sur la surface non exposée). Ces assemblages ont été réalisés en poteaux de bois et en poteaux d'acier léger. Deux sortes de plaques de plâtre ont été employées, soit les plaques de type X et les plaques ordinaires. On a évalué trois plaques de plâtre ordinaires de 12,7 mm d'épaisseur et de masses par unité de surface différentes, à savoir 7,82 kg/m^2, sans fibre de verre au coeur de la plaque; 7,35 kg/m^2, avec fibre de verre au coeur de la plaque; 7,27 kg/m^2, sans fibre de verre au coeur de la plaque. Les isolants mis à l'essai sont la fibre de verre, la fibre minérale et la fibre de cellulose (insufflée ou pulvérisée sous forme liquide).

Les chercheurs ont étudié les effets sur la résistance au feu d'assemblages muraux de l'orientation des plaques de plâtre, de la pose d'un profilé souple, du genre et de l'épaisseur de l'isolant mis en oeuvre dans la cavité murale, du type de poteau, de la masse par unité de surface des plaques de plâtre, de la présence de fibre de verre dans le coeur des plaques, de la méthode d'application de l'isolant cellulosique et de la profondeur de la cavité.

Les essais ont démontré ceci :

Effet de l'orientation des joints - Pour les assemblages muraux 1 sur 1, l'orientation des plaques de plâtre (joints verticaux ou horizontaux) a un effet mineur sur la capacité des assemblages à résister au feu. L'assemblage à joints verticaux offre une résistance au feu légèrement supérieure aux assemblages à joints horizontaux.

Effet des profilés souples - Pour les assemblages muraux 1 sur 1 et 2 sur 2 dotés de plaques de plâtre de type X, la pose de profilés souples sur la surface exposée ou non exposée, ou sur les deux surfaces, n'a pas d'effet significatif sur le comportement au feu comparativement à un assemblage dépourvu de profilés souples. Ces murs n'étaient pas porteurs et les joints des plaques de plâtre étaient appuyés.

Effets de l'isolant - fibre de verre - Les assemblages muraux 2 sur 2 comportant des plaques de plâtre légères courantes ayant une masse par unité de surface de 7,35 kg/m^2 et dont la cavité murale est isolée avec de la fibre de verre affichent une résistance au feu légèrement inférieure à celle d'un assemblage non isolé.

Pour ce qui est des assemblages muraux 1 sur 1, 1 sur 2 et 2 sur 2 réalisés avec des plaques de plâtre de type X, la pose d'isolant en fibre de verre n'a aucun effet sur le comportement au feu des assemblages par rapport à un assemblage non isolé.

Effets de l'isolant - fibre minérale - Dans le cas des assemblages muraux 1 sur 1, 1 sur 2 et 2 sur 2 dotés de plaques de plâtre de type X, la pose d'isolant en fibre minérale permet d'accroître la résistance au feu de 20 à 50 % par rapport à un assemblage non isolé.

L'épaisseur de l'isolant n'influe pas sur le comportement au feu des assemblages 1 sur 2 comportant des plaques de plâtre de type X d'une épaisseur de 12,7 mm et bénéficiant d'une isolation à la fibre minérale de 40 mm ou de 90 mm.

Un assemblage 2 sur 2 pourvu de plaques de plâtre de type X d'une épaisseur de 12,7 mm et dont la cavité murale est comblée avec un isolant en fibre minérale de 90 mm d'épaisseur augmente la résistance au feu de 18 % comparativement à un assemblage bénéficiant d'une isolation de 40 mm d'épaisseur.

Effets de l'isolant - fibre de cellulose - La pose d'isolant en fibre de cellulose dans la cavité murale des assemblages muraux 1 sur 1, 1 sur 2 et 2 sur 2 réalisés avec des plaques de plâtre de type X accroît de 22 % à 55 % le comportement au feu de ces assemblages par rapport à un assemblage non isolé.

Effets du genre de poteau - Dans le cas des assemblages muraux symétriques 2 sur 2 non isolés formés avec des plaques de plâtre ordinaires, et des assemblages asymétriques 1 sur 2 non isolés avec plaques de plâtre de type X composés de poteaux différents (bois et acier), l'assemblage en poteaux de bois permet une résistance au feu de 12 % supérieure à celle de l'assemblage en poteaux d'acier. On considère que le genre de poteau utilisé pour les assemblages 2 sur 2 a un léger effet sur le comportement au feu. Tous les assemblages qui ont servi aux essais étaient non porteurs.

Effet de la masse par unité de surface des plaques de plâtre - Pour les assemblages muraux 2 sur 2 non isolés formés avec des plaques de plâtre ordinaires de différentes masses par unité de surface (soit 7,82 kg/m^2 (environ 1.6 lb/pi^2) et 7,35 kg/m^2 (environ 1.5 lb/pi^2)), l'assemblage avec plaques de plâtre de 7,82 kg/m^2 offre une meilleure résistance au feu que l'autre. La masse par unité de surface des plaques de plâtre semble donc avoir un effet sur le comportement au feu des assemblages.

Effet de la présence de fibre de verre dans le coeur des plaques de plâtre - Dans les assemblages muraux 2 sur 2 non isolés, la présence de fibre de verre au coeur des plaques de plâtre ne modifie pas le comportement au feu des assemblages par rapport à un assemblage dont les plaques sont dépourvues de fibre de verre.

Effet de la méthode d'application de la fibre de cellulose - Un assemblage isolé avec de la fibre de cellulose insufflée permet une meilleure résistance au feu qu'un autre dont la fibre de cellulose a été pulvérisée sous forme liquide.

Effet de la profondeur de la cavité - Dans les assemblages asymétriques 1 sur 2 non isolés composés de plaques de plâtre de type X montées sur poteaux d'acier à différentes profondeurs de cavité (65 mm et 90 mm), la profondeur de la cavité n'influe pas sur le comportement au feu.

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RESULTS OF FIRE RESISTANCE TESTS ON SMALL-SCALE, INSULATED AND NON-INSULATED, GYPSUM BOARD PROTECTED WALL ASSEMBLIES

by

M. A. Sultan and G. D. Lougheed

EXECUTIVE SUMMARY

This report presents the results of 48 small-scale fire resistance tests conducted at the National Fire Laboratory on insulated and non-insulated, small-scale, gypsum board protected wall assemblies. Four assembly arrangements were studied: symmetrical installation 1x1 (one layer of gypsum board on both the exposed and unexposed sides); asymmetrical installation 1x2 (one layer of gypsum board on the exposed side and two layers of board on unexposed side); asymmetrical installation 2x1 (two layers of gypsum board on the exposed side and one layer of board on unexposed side); and symmetrical installation 2x2 (two layers of boards on each of the exposed and unexposed sides). The assemblies were constructed with wood and lightweight steel studs. Two gypsum board types, Type X and regular, were considered. Three 12.7 mm thick regular gypsum board products were evaluated with different mass per unit areas: 7.82 kg/m² with no glass fibre in the gypsum board core; 7.35 kg/m² with glass fibre in the gypsum board core; and 7.27 kg/m² with no glass fibre in the gypsum board core. The insulations tested were glass, mineral and cellulose (blown dry and wet spray) fibres.

The effects of gypsum board orientation, resilient channel installation, type and thickness of insulation in the wall cavity, stud type, mass/unit area of regular gypsum board, presence of glass fibre in regular gypsum board core, cellulose fibre insulation application method, and cavity depth on the fire resistance of wall assemblies were investigated.

The results of these tests showed:

Joint Orientation Effect – In (1x1) wall assemblies, the orientation of gypsum board application (horizontal or vertical joints) had a minor affect on the fire resistance performance of the wall assemblies. An assembly with a vertical joint orientation provided a slightly better fire resistance performance than an assembly with a horizontal joint orientation.

Resilient Channels Effect – In (1x1) and (2x2) wall assemblies, using Type X gypsum board, the installation of resilient channels on either the exposed or unexposed sides, or on both sides, did not have a significant impact on the fire performance compared to an assembly with no resilient channels. These assemblies were all non-loadbearing and the gypsum board joints were backed.

Insulation Effects – Glass Fibre – In (2x2) wall assemblies, using regular lightweight gypsum board with a mass per unit area of 7.35 kg/m², the fire resistance performance of an assembly with glass fibre insulation in the wall cavity was slightly lower than that of a non-insulated assembly.

In (1x1), (1x2) and (2x2) wall assemblies with Type X gypsum board, the installation of glass fibre insulation provided a neutral effect on the fire resistance performance compared to a non-insulated assembly.

Insulation Effects – Mineral Fibre – In (1x1), (1x2) and (2x2) wall assemblies with Type X gypsum board, the installation of mineral fibre insulation provided an increase in the fire resistance performance of 20% to 50% compared to a non-insulated assembly.

In (1x2) assemblies with 12.7 mm thick Type X gypsum board and different mineral fibre insulation thickness (40 mm and 90 mm), the thickness of the insulation did not play a role in the fire resistance performance.

An assembly (2x2) with a 12.7 mm thick Type X gypsum board and 90 mm thick mineral fibre insulation in the wall cavity provided an 18% increase in the fire resistance performance compared to an assembly with 40 mm thick insulation.

Insulation Effects – Cellulose Fibre – In (1x1), (1x2) and (2x2) wall assemblies with Type X gypsum board, the installation of cellulose fibre in the wall cavity provided an increase in the fire resistance performance of 22% to 55% compared to a non-insulated assembly.

Effects of Stud Type – In double layer (2x2) non-insulated regular gypsum board wall assemblies and in asymmetrical (1x2) non-insulated Type X gypsum board wall assemblies with different stud types (wood and steel), the assembly with wood studs provided a 12% better fire resistance performance than the assembly with steel studs. In (2x2) assemblies, it is considered that the type of studs has a slight effect on the fire resistance performance of assemblies. These were all non-loadbearing assemblies.

Effect of Gypsum Board Mass/unit Area – In double layer (2x2) non-insulated wall assemblies with regular gypsum board at different mass per unit areas: [7.82 kg/m^2 (approximately 1.6 lb/ft^2) and 7.35 kg/m^2 (approximately 1.5 lb/ft^2)], the assembly with gypsum board at 7.82 kg/m^2 provided a better fire resistance performance than the assembly with gypsum board at 7.35 kg/m^2. The mass per unit area of gypsum board, therefore, has an effect on the fire resistance performance of the assemblies.

Effect of the Presence of Glass Fibre in Gypsum Board Core – In double layer (2x2) non-insulated wall assemblies with and without glass fibre in the gypsum board core, the presence of glass fibre in the gypsum board core did not affect the fire resistance performance compared to an assembly without glass fibre in the gypsum board core.

Effect of Cellulose Fibre Application Method – An assembly with blown-dry cellulose fibre insulation provided a better fire resistance performance than an assembly with wet sprayed cellulose fibre insulation.

Effect of Cavity Depth – In asymmetrical (1x2) non-insulated assemblies with Type X gypsum board on steel studs at different cavity depths (65 mm and 90 mm), the cavity depth did not effect the fire resistance performance.

RESULTS OF FIRE RESISTANCE TESTS ON SMALL-SCALE, INSULATED AND NON-INSULATED, GYPSUM BOARD PROTECTED WALL ASSEMBLIES

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A number of recent changes to the 1990 edition of the National Building Code of Canada (NBCC) [1] and to the CAN/CSA-A82.27-M91 Standard "Gypsum Board-Building Materials and Products" [2] may have an effect on the fire performance of insulated and non-insulated gypsum board wall assemblies. One of the major issues is that the requirement for weight per unit area for gypsum board products has been removed. As well, there have been changes in the NBCC to increase the sound transmission ratings (STC) between dwelling units. Either or both of these changes may have an impact on the fire resistance of both wall and floor assemblies referenced in Parts 3 and 9 of the NBCC, as well as the calculation methods in Chapter 2 of the Supplement to the NBCC.

As a result of these changes, a Joint Research Project between IRC/NRCC and 8 industry partners was conducted with the primary objective of determining the impact that the various changes to the codes and standards may have had on the fire resistance ratings of insulated and non-insulated gypsum board-protected wall assemblies. To evaluate these possible effects, a number of full- and small-scale fire tests were conducted.

This report presents the results of 48 small-scale fire tests conducted at the National Fire Laboratory (NFL) of the Institute for Research in Construction (IRC), National Research Council Canada (NRCC), as part of the Joint Research Project. These tests investigated the effects of gypsum board joint orientation, resilient channel installation, type and thickness of insulation in the wall cavity, stud type, mass/unit area of regular gypsum board, presence of glass fibre in regular gypsum core, cellulose fibre insulation application methods, and cavity depth on the fire resistance of small-scale wall assemblies. The results of the tests on the small-scale assemblies are analyzed and presented. The results of the full-scale fire resistance tests are presented in a separate report [3].

2.0 DESCRIPTION OF TEST ASSEMBLIES

The small-scale test furnace set-up is shown in Figure 1.

2.1 Dimensions

Forty-eight assemblies, 914 mm high by 914 mm wide, were constructed with various depths. The specific dimensions of each assembly are given in Figures 2 to 48.

2.2 Materials

<u>Gypsum Board</u>

Type X and regular gypsum board, conforming to the requirements of CAN/CSA-A82.27-M91 [2], were used. Three 12.7 mm thick regular gypsum board types were evaluated: the first had no glass fibre in the gypsum core with a mass/unit area of 7.82 kg/m², the second was lower density, regular gypsum board and glass fibre in the gypsum board core with a mass/unit area of 7.35 kg/m², and the third had a lower density, regular gypsum board and no glass fibre in the gypsum board core with a mass/unit area of 7.27 kg/m². The thicknesses of the Type X gypsum board used in the assemblies were 12.7 mm and 15.9 mm.

Framing Materials

The steel studs used conformed to CAN/CGSB-7.1 [4] and the wood framing members were nominal 2x4's (38 mm thick by 89 mm deep) and conformed to CSA 0141-1970 [5].

Resilient Channels

The resilient channels used in the assemblies were sections of 0.18 mm thick galvanized steel. These channels consisted of a 34 mm web and one flattened 18 mm flange lip (see Figure 49). The flange between the web and flattened lip was perforated with 36 mm oblong holes.

Insulation

Three types of insulation were used: Glass Fibre-R12 (supplied by Fiberglas Canada Inc., Willowdale, Ontario with a mass per unit area of 1.08 kg/m²); Mineral Fibre Roxul-R13 (supplied by Roxul Inc., Milton, Ontario with a mass per unit area of 2.78 kg/m²); and Cellulose Fibre dry blown and wet sprayed (supplied by Thermo-Cell Insulation Ltd., Orleans, Ontario with a mass per unit area of 4.57 kg/m² and 5.25 kg/m² for wood stud and steel stud assemblies, respectively). All of the types of insulation used satisfy CSA A101 [6].

2.3 Fabrication

The small-scale assemblies were constructed using similar construction practices to those employed for the full-scale fire test assemblies. All small-scale tests were non-loadbearing. All assemblies were constructed by the same contractor using the same construction practices.

Wood Stud Assemblies

The wood studs used were 38 mm by 89 mm for all wood stud assemblies except for Assembly S-40 in which they were 38 mm by 65 mm (SPF No. 1 and No. 2, S-Dry, QLMA Mill Grade 149 supplied by Forintek Canada Corp.). The studs were spaced at 600 mm O.C. in Assembly S-02 and at 400 mm O.C. in all other wood stud assemblies. To make up the required furnace width of 914 mm, an additional stud was added to each end. The top and bottom plates were then added to complete the assembly.

In single layer assemblies (1x1) with wood studs spaced at 400 mm O.C., the gypsum board was attached to the wood studs with Type S drywall screws, 41 mm long, spaced at 400 mm O.C. along the edges and in the field of the board. Screw locations and gypsum board joints are shown in Figure 50 [7]. Screw heads on both the exposed and unexposed faces were covered with joint compound. Gypsum board joints were also taped and covered with joint compound.

In double layer assemblies (2x2) with wood studs spaced at 400 mm O.C., both the exposed and unexposed sides had two gypsum board layers: base and face layers. The base layer was attached to wood studs with Type S drywall screws, 41 mm long, spaced at 600 mm O.C. in the field of the board and along the edges. The face layer was attached to both the base layer and the studs with drywall screws, 51 mm long, spaced at 400 mm O.C. along the edges and in the field of the board. Screw locations and gypsum board joints are shown in Figure 51 [7]. Screw heads on both the exposed and unexposed faces were covered with joint compound. Gypsum board joints on the face layer were also taped and covered with joint compound.

In double layer assemblies (2x2) with wood studs spaced at 600 mm O.C., both the exposed and unexposed sides had two gypsum board layers: base and face layers. The base layer was attached to the wood studs with Type S drywall screws, 41 mm long, spaced at 600 mm O.C. in the field of the board and along the edges. The face layer was attached to both the base layer and the studs with drywall screws, 51 mm long, spaced at 300 mm O.C. along the edges and in the field of the board. Screw locations and gypsum board joints are shown in Figure 52 [7]. Screw heads on both the exposed and unexposed faces were covered with joint compound. Gypsum board joints on the face layers were also taped and covered with joint compound.

In asymmetrical installation (1x2) assemblies with wood studs spaced at 400 mm O.C., the exposed side had one gypsum board layer and the unexposed side had two gypsum board layers: base and face layers. The base layer on the unexposed side was attached to the wood studs with Type S drywall screws, 41 mm long, spaced at 600 mm O.C. in the field of the board and along the edges. The face layer was attached to both the base layer and wood studs with drywall screws, 51 mm long, spaced at 400 mm O.C. The gypsum board layer on the exposed side was attached to wood studs with Type S drywall screws, 41 mm long, spaced at 400 mm O.C. along the edges and in the field of the board. Screw locations and gypsum board joints are shown in Figure 53 [7]. Screw heads on both the exposed and unexposed faces were covered with joint compound. Gypsum board joints were also taped and covered with joint compound.

Steel Stud Assemblies

The steel studs were light C sections (65 mm by 30 mm by 0.6 mm in Assembly S-39 and 90 mm by 30 mm by 0.6 mm in all other steel stud assemblies) and were spaced at 600 mm O.C. To make up the required furnace width of 914 mm, an additional stud was added to each end. The top and bottom runners were then added to complete the assembly. In order to maintain the integrity of the assembly, the steel studs were fastened to the top and bottom runners.

In single layer assemblies (1x1) with steel studs spaced at 600 mm O.C., the gypsum board was attached to the steel studs with Type S drywall screws, 25 mm long, spaced at 300 mm O.C. along the edges and in the field of the board. Screw locations and gypsum board joints are shown in Figure 54 [7]. Screw heads on both the exposed and unexposed faces were covered with joint compound. Gypsum board joints were also taped and covered with joint compound.

In double layer assemblies (2x2) with steel studs spaced at 600 mm O.C., both the exposed and unexposed sides had two gypsum board layers: base and face layers. The base layer was attached to the steel studs with Type S drywall screws, 25 mm long, spaced at 600 mm O.C. in the field of the board and spaced at 300 mm O.C. along the edges of the board. The face layer was attached to both the base layer and steel studs with drywall screws, 41 mm long, spaced at 300 mm O.C. along the edges and in the field of the board. Screw locations and gypsum board joints are shown in Figure 55 [7]. Screw heads on both the exposed and unexposed faces were covered with joint compound. Gypsum board joints, on the face layers, were also taped and covered with joint compound.

In asymmetrical installation (1x2) assemblies, the exposed side had one gypsum board layer and the unexposed side had two gypsum board layers: base and face layers. The base layer on the unexposed side was attached to the steel studs with Type S drywall screws, 25 mm long, spaced at 600 mm O.C. in the field and spaced at 300 mm O.C. along the edges of the board. The face layer on the unexposed side was attached to both the base layer and steel studs with drywall screws, 41 mm long, spaced at 300 mm O.C along the edges of the gypsum board and in the field of the board. The gypsum board layer on the exposed side was attached to steel studs with Type S drywall screws, 25 mm long, spaced at 300 mm O.C. along the edges and in the field of the board. Screw locations and gypsum board joints are shown in Figure 57 [7]. Screw heads on both the exposed and unexposed faces were covered with joint compound. Gypsum board joints were also taped and covered with joint compound.

In asymmetrical installation (2x1) assemblies, the exposed side had two gypsum board layers: base and face layers and the unexposed side had one gypsum board layer. The base layer on the exposed side was attached to the steel studs with Type S drywall screws, 25 mm long, spaced at 600 mm O.C. in the field and spaced at 300 mm O.C. along the edges of the board. The face layer on the exposed side was attached to both the base layer and steel studs with drywall screws, 41 mm long, spaced at 300 mm O.C. The gypsum board layer on the unexposed side was attached to the steel studs with Type S drywall screws, 25 mm long, spaced at 300 mm O.C. along the edges and in the field of the board. Screw locations and gypsum board joints are shown in Figure 57 [7]. Screw heads on both the exposed and unexposed faces were covered with joint compound. Gypsum board joints were also taped and covered with joint compound.

Insulation

Mineral fibre and glass fibre insulation batts were supplied in sizes 90 mm thick by 615 mm wide by 1220 mm long. The cellulose fibre insulation was extruded into the cavity (blind dry fill and wet spray), after the installation of the thermocouples.

Resilient Channel Installation

The resilient channels were attached to either the exposed or unexposed side of the wood studs, or both, with 25 mm long, self-drilling, self-tapping steel screws spaced at 300 mm O.C. Three rows of channels were installed horizontally, perpendicular to the studs, at 400 mm O.C. using similar construction practices to those specified in ULC Assembly U-311 [8]. In this construction, the gypsum board joints are horizontal and are backed by the resilient channel. (For full-scale wall assemblies, there are vertical joints which are unbacked. These joints were not simulated in the small-scale assemblies.) The gypsum board was attached to the channels with 32 mm long steel screws spaced at 300 mm O.C. Normal construction practices were used for the installation of gypsum board on the side without resilient channels. At both ends, the channels were cut 39 mm shorter than the width of the assembly in order to avoid heat and flame transmission to the unexposed surface. The gaps created at the ends of the channels were filled with strips of gypsum board facing screwed to the outer edge studs.

2.4 Instrumentation

Type K (20 gauge) chromel-alumel thermocouples, with a thickness of 0.91 mm, were used for measuring temperatures at a number of locations throughout an assembly. Inside the cavities, the thermocouples were attached to 2 wire hangers installed midway between the studs and at mid depth of the studs at distances of 1/4 and 3/4 of the height of the wall. By providing tension to the hanger wire, the thermocouples were positioned flush with the surface of the gypsum board.

Thermocouples located at the interface between the studs and the gypsum board and those located between gypsum board layers were taped into position and then the gypsum board was screwed to the stud or the face layer.

Thermocouple locations are shown for each assembly in Figures 2 to 48.

3.0 TEST APPARATUS

The tests were carried out by exposing the assemblies to heat in a propane-fired, vertical furnace with an 810 by 810 mm opening. The furnace was lined with fire brick covered with a 2.5 cm thick ceramic fibre insulation blanket. The assemblies were sealed at the edges against the furnace with ceramic fibre blanket. The furnace temperature was measured by two 20 gauge shielded thermocouples, located near the vertical centreline of the furnace and 300 mm back from the exposed surface of the assembly. The average of the two thermocouple temperatures was used to control the furnace temperature.

4.0 TEST CONDITIONS AND PROCEDURES

4.1 Fire Exposure

The ambient temperature at the start of each test was approximately 22°C. During the test, the wall assembly was exposed to heating on the exposed side in such a way that the average temperature in the furnace followed, as closely as possible, the CAN/ULC-S101-M89 [9] standard temperature-time curve.

4.2 Failure Criteria

The failure criteria for the small-scale tests were derived from CAN/ULC-S101-M89 [9]. The assembly was considered to have failed if a single point thermocouple temperature reading on the unexposed face rose above 180°C or the average temperature of the 5 thermocouples readings under the insulated pads on the unexposed face (see Figure 58) rose 140°C above the ambient temperature or there was passage of flame or gases hot enough to ignite cotton waste. The tests were run beyond the failure temperature, referred to above, to provide additional performance data.

4.3 Recording of Results

The furnace and wall assembly temperatures were recorded at 1 minute intervals using LABTECH NOTEBOOK data acquisition software and a Fluke Helios-I data acquisition system.

5.0 RESULTS AND DISCUSSION

The results of the 48 small-scale fire tests are summarized in Table 1 in which the single point and average failure times are given for each assembly. The effects of gypsum board joint orientation, resilient channel installation, type and thickness of insulation in the wall cavity, stud type, mass/unit area of regular gypsum board core, presence of glass fibre in regular gypsum board, cellulose fibre insulation application method, and cavity depth, on the fire resistance of wall assemblies are discussed below. Details on temperature measurements throughout the assemblies are given in References [10 to 13].

5.1 Effects of Joint Orientation and Resilient Channels

The fire resistance performance of insulated and non-insulated, small-scale assemblies with and without resilient channel installations are presented in Figures 59-75.

Joint Orientation – Tests S-08 and S-35 were conducted to determine whether the orientation of gypsum board application (horizontal or vertical joints) has an effect on the fire resistance performance of the assemblies as shown in Figure 59. In Test S-08, the gypsum board had a horizontal joint at the mid-height of the wall on the exposed side and in Test S-35, the gypsum board had a vertical joint at the mid-width of the wall on the exposed side. In the latter test, the joint was backed by the steel stud, whereas in Test S-08, the joint was unbacked. The temperature failure criterion was reached at 46 min for Test S-08 and at 49 min for Test S-35. The difference of 3 min in the fire resistance performance of the assemblies is considered to be slightly more than the systematic error of the test method. Therefore, the gypsum board joint orientation did play a role in the fire performance. It must be noted that these tests were non-loadbearing.

Resilient Channels – Tests S-05, S-06, S-07 and S-08 were conducted with single layer non-insulated gypsum board wall assemblies to investigate the effect of resilient channel installation on the fire resistance performance of the assemblies. In Test S-05, the resilient channels were installed on the exposed side. In Test S-06, the resilient channels were installed on the unexposed side and in Test S-07 the resilient channels were installed on both the exposed and unexposed sides. Test S-08 was constructed without resilient channels. The results for the tests given in Table 1 and shown in Figure 60 are all within the systematic error of the test method. This suggests that in (1x1) small-scale gypsum board wall assemblies, the installation of resilient channels on the exposed, the unexposed or both sides did not significantly affect the fire resistance performance of assemblies compared to an assembly without resilient channels.

Tests S-36, S-37 and S-38 were conducted to investigate the effect of installation of the resilient channels on the fire resistance performance of double layer (2x2), non-insulated gypsum board wall assemblies. Test S-36 was a baseline test with no resilient channels. In Test S-37, the resilient channels were installed on the exposed side while in Test S-38, the resilient channels were installed on both the exposed and unexposed sides. The temperature failure criterion was reached at 142 min for Test S-36 (without resilient channels), at 141 min for Test S-37 (with resilient channels on the fire exposed side) and at 144 min for Test S-38 (with resilient channels on both, exposed and unexposed sides). The results, given in Table 1 and shown in Figure 61, suggest that in double layer 12.7 mm thick Type X gypsum wallboard assemblies, the installation of resilient channels did not affect the fire resistance performance of assemblies compared to an assembly without resilient channels. Variations in the results were within the systematic error of the test method.

5.2 Effects of Insulation Type

Insulation in 2x2 (12.7 mm Thick Regular Lightweight Gypsum Board) Wall Assemblies (Figure 62)

Glass fibre insulation (GFI) – Tests S-32 (GFI) and S-01B (non-insulated) were carried out to investigate the effect of the installation of glass fibre insulation in the wall cavity on the fire resistance of a double layer, regular lightweight gypsum board wall assembly. The temperature failure criterion was reached at 74 min for Test S-32 and at 82 min for Test S-01B. These results indicate that for double layer assemblies, the glass fibre insulation has a negative effect on the fire resistance performance of the assembly compared to a non-insulated assembly.

With the small-scale tests, failure is predominantly due to heat transfer through the gypsum board layers. With the glass fibre insulation in the wall cavity, there is a more rapid temperature increase in the gypsum board on the fire-exposed side. As a result, the rate of calcination of the regular gypsum board increases and causes premature failure/splitting of the gypsum board layers on the fire-exposed side thus exposing the wall cavity to direct flames at an earlier time in the test. The resulting exposure of the gypsum board on the unexposed side leads to an earlier failure of the assembly.

Mineral Fibre Insulation (MFI) – Tests S-33 and S-01B were conducted to investigate the effect of the mineral fibre insulation in the wall cavity. The temperature failure criterion was reached at 98 min for Test S-33 and at 82 min for Test S-01B. These results suggest that in small-scale double layer assemblies, the installation of the 40 mm thick mineral fibre insulation in the wall cavity provided a 20% increase in the fire resistance performance compared to a non-insulated assembly.

Cellulose Fibre Insulation (CFI) – Tests S-34 and S-01B were conducted to investigate the effect of the installation of CFI (blown dry) in the wall cavity. The temperature failure criterion was reached at 102 min for Test S-34 and at 82 min for Test S-01B. These results suggest that, in small-scale double layer, regular lightweight gypsum board assemblies, the installation of 90 mm thick cellulose fibre insulation (blown dry) provided a 24% increase in the fire resistance performance compared to a non-insulated assembly.

<u>Insulation in 1x1 (12.7 mm Thick Type X Gypsum Board) Wall Assemblies (Figure 63)</u>

Glass Fibre Insulation (GFI) – Tests S-09 (non-insulated) and S-22 (GFI) were carried out to investigate the effect of glass fibre insulation in the wall cavity. The temperature failure criterion was reached at 46 min for Test S-09 and at 46 min for Test S-22. These results suggest that, in small-scale single layer, 12.7 mm thick Type X gypsum board wall assemblies, the installation of 90 mm thick GFI in the wall cavity did not affect the fire resistance performance compared to a non-insulated assembly.

Mineral Fibre Insulation (MFI) – Tests S-09 (non-insulated) and S-14 (MFI) were conducted to investigate the effect of the installation of mineral fibre insulation in the wall cavity. The temperature failure criterion was reached at 46 min for Test S-09 and at 69 min for Test S-14. These results suggest that, in small-scale single layer, 12.7 mm thick Type X gypsum board wall assemblies, the installation of 40 mm thick mineral fibre insulation in the wall cavity provided a 50% increase in the fire resistance performance compared to a non-insulated assembly.

Cellulose Fibre Insulation (CFI) – Tests S-09 (non-insulated) and S-15 (CFI blown dry) were carried out to investigate the effect of installation of cellulose fibre insulation in the wall cavity. The temperature failure criterion was reached at 46 min for Test S-09 and at 69 min for Test S-15. These results suggest that, in small-scale single layer, 12.7 mm thick Type X gypsum board wall assemblies, the installation of 90 mm thick cellulose fibre insulation in the wall cavity provided a 50% increase in the fire resistance performance compared to a non-insulated assembly.

Insulation in 1x2 (12.7 mm Thick Type X Gypsum Board) Wall Assemblies (Figure 64)

Glass Fibre Insulation (GFI) – Tests S-10 (non-insulated) and S-23 (GFI) were carried out to investigate the effect of glass fibre insulation in the wall cavity. The temperature failure criterion was reached at 86 min for Test S-10 and at 88 min for Test S-23. These results suggest that, in asymmetrical (1x2), 12.7 mm thick Type X gypsum board small-scale assemblies, the installation of 90 mm thick glass fibre insulation in the wall cavity did not significantly affect the fire resistance performance compared to a non-insulated assembly.

Mineral Fibre Insulation (MFI) – Tests S-10 (non-insulated) and S-26 (MFI) were conducted to investigate the effect of the installation of mineral fibre insulation in the wall cavity. The temperature failure criterion was reached at 86 min for Test S-10 and at 114 min for Test S-26. These results suggest that, in small-scale asymmetrical (1x2), 12.7 mm thick Type X gypsum board assemblies, the installation of 90 mm thick mineral fibre insulation in the wall cavity provided a 33% increase in the fire resistance performance compared to a non-insulated assembly.

Cellulose Fibre Insulation (CFI) – Tests S-10 (non-insulated) and S-18 (CFI blown dry) were carried out to investigate the effect of installation of cellulose fibre insulation in the wall cavity. The temperature failure criterion was reached at 86 min for Test S-10 and at 134 min for Test S-18. These results suggest that, in small-scale asymmetrical (1x2), 12.7 mm thick Type X gypsum board wall assemblies, the installation of cellulose fibre insulation in the wall cavity provided a 56% increase in the fire resistance performance compared to an assembly with no insulation in the cavity.

Insulation in 2x2 (12.7 mm Thick Type X Gypsum Board) Wall Assemblies (Figure 65)

Glass Fibre Insulation (GFI) – Tests S-12 (non-insulated) and S-25 (GFI) were carried out to investigate the effect of GFI in the wall cavity. The temperature failure criterion was reached at 129 min for Test S-12 and at 139 min for Test S-25. These results suggest that, in small-scale double layer installations (2x2) of 12.7 mm thick Type X gypsum board assemblies, the installation of 90 mm thick glass fibre insulation in wall cavity provided an 8% increase in the fire resistance performance compared to a non-insulated assembly.

Mineral Fibre Insulation (MFI) – Tests S-12 (non-insulated) and S-27 (MFI) were conducted to investigate the effect of the installation of mineral fibre insulation in the wall cavity. The temperature failure criterion was reached at 129 min for Test S-12 and at 160 min for Test S-27. These results suggest that, in small-scale double layer installations of 12.7 mm thick Type X gypsum board wall assemblies, the installation of 90 mm thick mineral fibre insulation in the wall cavity provided a 24% increase in the fire resistance performance compared to a non-insulated assembly.

Cellulose Fibre Insulation (CFI) – Tests S-12 (non-insulated) and S-21 (CFI blown dry) were carried out to investigate the effect of the installation of cellulose fibre insulation in the wall cavity. The temperature failure criterion was reached at 129 min for Test S-12 and at 157 min for Test S-21. These results suggest that, in (2x2) double layer installations of 12.7 mm thick Type X gypsum board wall assemblies, the installation of cellulose fibre insulation in the wall cavity provided a 22% increase in the fire performance compared to a non-insulated assembly.

Insulation in 1x2 (15.9 mm Thick Type X Gypsum Board) Wall Assemblies (Figure 66)

Glass Fibre Insulation (GFI) – Tests S-41 (non-insulated) and S-44 (GFI) were carried out to investigate the effect of glass fibre insulation in the wall cavity. The temperature failure criterion was reached at 136 min for Test S-41 and at 133 min for Test S-44. These results suggest that, in asymmetrical installations of 15.9 mm thick Type X gypsum board small-scale wall assemblies, the installation of 90 mm thick glass fibre insulation in the wall cavity did not significantly affect the fire performance compared to a non-insulated assembly.

Mineral Fibre Insulation (MFI) – Tests S-41 (non-insulated) and S-42 (MFI) were conducted to investigate the effect of the installation of mineral fibre insulation in the wall cavity. The temperature failure criterion was reached at 136 min for Test S-41 and at 135 min for Test S-42. These results suggest that, in asymmetrical installations of 15.9 mm thick Type X gypsum board, the installation of mineral fibre insulation in the wall cavity did not significantly affect the fire performance compared to a non-insulated assembly. With the small-scale tests, failure is predominantly due to heat transfer through the gypsum board layers. With the MFI in the wall cavity, there is a more rapid temperature increase in the gypsum board on the fire-exposed side. As a result, the rate of calcination of the gypsum board increases and causes premature failure/splitting of the gypsum board layer on the fire-exposed side and thus exposed the MFI to direct flames. As the MFI batts remained intact in the wall cavity for some time, it provided a fire resistance protection to the unexposed gypsum board layer more or less equal to the fire resistance protection lost due an early splitting of the gypsum board layer on the fire exposed side.

Cellulose Fibre Insulation (CFI) – Tests S-41 (non-insulated) and S-43 (CFI blown dry) were carried out to investigate the effect of installation of cellulose fibre insulation in the wall cavity. The temperature failure criterion was reached at 136 min for Test S-41 and at 113 min for Test S-43. These results suggest that, in (1x2) asymmetrical installations of 15.9 mm thick Type X gypsum board, the installation of 90 mm thick cellulose fibre insulation in the wall cavity provided a 17% decrease in the fire performance compared to a non-insulated assembly. With the small-scale tests, failure is predominantly due to heat transfer through the gypsum board layers. With the CFI in the wall cavity, there is a more rapid temperature increase in the gypsum board on the fire-exposed side. As a result, the rate of calcination of the gypsum board increases and causes premature failure/splitting of the gypsum board layer on the fire-exposed side and thus exposed the CFI to direct flames. It was observed during the test that, when a piece of the gypsum board 400 mm long and 15 mm high on the fire-exposed side cracked and fell, the CFI behind it in the wall cavity was completely consumed. Therefore, there was no CFI to protect the gypsum board on the unexposed side and the resulting exposure of it led to an earlier failure of the assembly.

5.3 Effects of Different Insulation Thicknesses

Mineral Fibre Insulation (MFI) – Tests S-17 (40 mm thick MFI) and S-26 (90 mm thick MFI) and Tests S-20 (40 mm thick MFI) and S-27 (90 mm thick MFI) (see Figures 67 and 68) were conducted to investigate the effect of mineral fibre insulation thickness on the fire performance of (1x2) and (2x2) Type X gypsum board wall assemblies, respectively. The temperature failure criterion was reached at 110 min for Test S-17 compared to 114 min for Test S-26; and at 136 min for Test S-20 compared to 160 min for Test S-27. As shown in Figures 67 and 68, the results suggest that, in small-scale (1x2) assemblies, the thickness of MFI did not affect the fire performance of the assemblies while in (2x2) assemblies, the assembly with 90 mm thick MFI provided an18% better fire performance than the assembly with 40 mm thick MFI.

Cellulose Fibre Insulation (CFI) –Tests S-46 (90 mm thick CFI) and S-47 (40 mm thick CFI) were carried out to investigate the effect of thickness of cellulose fibre insulation (wet sprayed) in the wall cavity on the fire performance of (1x2) asymmetrical installations of 12.7 mm thick Type X gypsum board wall assemblies. The temperature failure criterion was reached at 95 min for Test S-46 and at 108 min for Test S-47. As shown in Figure 69, the results suggest that, in (1x2) gypsum board wall assemblies, the assembly with 40 mm thick CFI provided a 14% better fire performance than the assembly with 90 mm thick CFI.

5.4 Effects of Stud Type

The fire performance of (2x2) regular lightweight gypsum board and (1x2) Type X gypsum board on wood and steel studs in non-insulated wall assemblies is shown in Figures 70 and 71, respectively.

Tests S-02 (wood studs) and S-01B (steel studs) with 2x2 regular gypsum board and S-31 (wood studs) and S-10 (steel studs) with Type X gypsum board were carried out to investigate the effect of stud type on the fire performance of small-scale wall assemblies. The temperature failure criterion was reached at 88 min for Test S-02 as compared to 82 min for Test S-01B; and at 96 min for Test S-31 as compared to 86 min for Test S-10. These results suggest that, in small-scale (2x2) regular lightweight gypsum board and (1x2) Type X gypsum board wall assemblies, the fire resistance performance of assemblies with wood studs is 7 to 12% better than assemblies with steel studs. It must be noted that these were non-loadbearing assemblies.

5.5 Effects of Mass/Unit Area of Regular Gypsum Board

The fire performance of two 12.7 mm thick regular gypsum board products at different mass/unit area in non-insulated assemblies is shown in Figure 72.

Tests S-03 (7.82 kg/m^2) and S-01B (7.35 kg/m^2) were conducted to investigate the effect of using different mass/unit area of regular gypsum board on the fire performance of double layer gypsum board small-scale wall assemblies. The temperature failure criterion was reached at 104 min for Test S-03 and at 82 min for Test S-01B. These results suggest that, in small-scale double regular gypsum board wall assemblies, the reduction in the mass/unit area caused a 21% negative effect on the fire resistance performance of the assemblies.

5.6 Effects of Glass Fibre in Regular Lightweight Gypsum Board Core

The fire performance of (2x2) 12.7 mm thick (7.35 k/m^2) regular lightweight gypsum board with and without glass fibre in the core in non-insulated wall assemblies is shown in Figure 73.

Tests S-02 and S-49 were carried out to investigate the effect of the presence of glass fibre in the gypsum core on the fire performance of double layer regular gypsum board small-scale wall assemblies. The temperature failure criterion was reached at 87 min in Test S-49 (no glass fibre in the gypsum core) and at 88 min in Test S-02 (with glass fibre in the gypsum core). These results suggest that, in small-scale double layer wall assemblies, the presence of glass fibre in lightweight regular gypsum board did not affect the fire performance of the assemblies.

5.7 Effects of Cellulose Fibre Insulation Application Method

The fire performance of (1x2) insulated wall assemblies, with blown dry and wet spray cellulose fibre insulation is shown in Figure 74.

Tests S-10 (non-insulated), S-18 (blown dry CFI) and S-46 (wet spray CFI) were carried out to investigate the effect of the application method (blown dry and wet spray) of cellulose fibre insulation on the fire performance of 1x2 layer, 12.7 mm thick Type X gypsum board, small-scale wall assemblies. The temperature failure criterion was reached at 86 min for Test S-10 (non-insulated), at 95 min for Test S-46 (CFI wet spray application) and at 134 min for Test S-18 (CFI blown dry application). These results showed that, in small-scale (1x2), 12.7 mm thick Type X gypsum board wall assemblies, the assembly with blown dry CFI provided a 41% better fire resistance performance than the assembly with wet spray. When the wet cellulose insulation was allowed to dry to achieve a 10% moisture content, the insulation stuck to the gypsum board. As the gypsum board on the exposed side cracked and fell due to fire exposure, the insulation was removed with it which left the gypsum board on the unexposed side unprotected. This suggests that the method of application for cellulose fibre insulation has an effect on the fire performance of 1x2 small-scale assemblies.

5.8 Effect of Cavity Depth

Tests S-10 (90 mm cavity wide), S-39 and S-40 (65 mm cavity wide) were conducted on asymmetrical (1x2) non-insulated assemblies, using 12.7 mm thick Type X gypsum board, to determine the effect of cavity depth on the fire performance of assemblies. Assemblies S-10 and S-39 were constructed with steel studs and S-40 with wood studs. The temperature failure criterion was reached at 86 min for Test S-10, at 88 min for Test S-39 (Figure 75) and at 86 min for Test S-40. These results suggest that, the cavity depth (65 to 90mm) did not affect the fire performance of small-scale assemblies.

6.0 CONCLUSIONS

The results of the non-loadbearing small-scale wall tests conducted showed:

1. The gypsum board orientation had a minor effect on the fire resistance of small-scale assemblies. An assembly with vertical joint orientation provided a better fire resistance than an assembly with horizontal joint orientation.
2. Resilient channel installations on either the exposed or unexposed side or both sides did not play a significant role in fire resistance.
3. Glass fibre insulation in the wall cavity provided a neutral effect on fire resistance, except for assemblies with regular gypsum board.
4. Mineral fibre insulation in the wall cavity provided a 20% to 50% increase in the fire resistance when compared to non-insulated assemblies.
5. Cellulose fibre insulation provided a 22% to 55% increase in the fire resistance compared to non-insulated assemblies.
6. Wood studs provided a 12% better fire resistance than steel studs.
7. The presence of glass fibre in the gypsum board core of (2x2) assemblies did not affect the fire resistance for lightweight regular gypsum board.
8. An assembly with blown dry cellulose fibre insulation provided a 41% increase in the fire resistance compared to an assembly with wet sprayed cellulose fibre insulation.
9. The effect of cavity depth (65 mm to 90 mm) in steel stud assemblies was insignificant.

7.0 REFERENCES

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Table 1. Small-Scale Assembly Parameters and Fire Test Results

Assembly Number	Stud Type	Stud Size (mm)	Stud Spacing (mm)	Gypsum Board Layers (Exp/Unexp.)	Gypsum Board Thickness (mm)	Gypsum Board Type	Insulation Type	Insulation Thickness (mm)	Resilient Channel	Point Failure (min)	Average Failure (min)
S-01B	Steel	90	600	2X2	12.7	RL	***	***	***	82	84
S-01C	Steel	90	600	2X2	12.7	RL	***	***	***	86	***
S-02	Wood	89	600	2X2	12.7	RL	***	***	***	88	90
S-03	Steel	90	600	2X2	12.7	RH	***	***	***	104	105
S-04	Steel	90	600	1X1	15.9	X	***	***	***	64	64
S-05	Wood	89	400	1X1	12.7	X	***	***	E	48	48
S-06	Wood	89	400	1X1	12.7	X	***	***	U	45	47
S-07	Wood	89	400	1X1	12.7	X	***	***	E/U	48	49
S-08	Wood	89	400	1X1	12.7	X	***	***	***	46	47
S-09	Steel	90	600	1X1	12.7	X	***	***	***	46	46
S-10	Steel	90	600	1X2	12.7	X	***	***	***	86	86
S-11	Steel	90	600	2X1	12.7	X	***	***	***	85	86
S-12	Steel	90	600	2X2	12.7	X	***	***	***	129	129
S-14	Steel	90	600	1X1	12.7	X	MF	40	***	69	72
S-15	Steel	90	600	1X1	12.7	X	CFI	90	***	69	71
S-17	Steel	90	600	1X2	12.7	X	MF	40	***	110	112
S-18	Steel	90	600	1X2	12.7	X	CFI	90	***	134	135
S-20	Steel	90	600	2X2	12.7	X	MF	40	***	136	140
S-21	Steel	90	600	2X2	12.7	X	CFI	90	***	157	163
S-22	Steel	90	600	1X1	12.7	X	GF	90	***	46	48
S-23	Steel	90	600	1X2	12.7	X	GF	90	***	88	93
S-24	Steel	90	600	2X1	12.7	X	GF	90	***	98	102
S-25	Steel	90	600	2X2	12.7	X	GF	90	***	139	139
S-26	Steel	90	600	1X2	12.7	X	MF	90	***	114	117

X - Type X Gypsum12.7 mm Thick (7.83 kg/m²) and 15.0 mm Thick (11.00 kg/m²)

RL - Low Density Regular Gypsum Board (7.35 kg/m²)   RH - Regular Gypsum Board, no Glass Fibre in Gypsum Board (7.82 kg/m²)

RL - Low Density Regular Gypsum Board no Glass Fibre in Gypsum Board (7.35 kg/m²)   E - Exposed Side   U - Unexposed Side

GF - Glass Fibre Insulation   MF - Mineral Fibre Insulation   CFI - Cellulosic Fibre Insulation(Blown Dry)   CFI* - (Wet Sprayed)

*** - Null Value

Table 1. (Continued)

Assembly Number	Stud Type	Stud Size (mm)	Stud Spacing (mm)	Gypsum Board Layers (Exp/Unexp.)	Gypsum Board Thickness (mm)	Gypsum Board Type	Insulation Type	Insulation Thickness (mm)	Resilient Channel	Point Failure (min)	Average Failure (min)
S-27	Steel	90	600	2X2	12.7	X	MF	90	***	160	162
S-28	Wood	89	400	1X2	12.7	X	GF	90	E	92	96
S-29	Wood	89	400	1X2	12.7	X	MF	90	E	125	129
S-30	Wood	89	400	1X2	12.7	X	CFI	90	E	164	165
S-31	Wood	89	400	1X2	12.7	X	***	***	E	96	96
S-32	Steel	90	600	2X2	12.7	RL	GF	90	***	74	76
S-32B	Steel	90	600	2X2	12.7	RL	GF	90	***	72	73
S-33	Steel	90	600	2X2	12.7	RL	MF	90	***	98	101
S-34	Steel	90	600	2X2	12.7	RL	CFI	90	***	102	***
S-35	Wood	89	400	1X1	12.7	X	***	***	***	49	49
S-36	Wood	89	400	2X2	12.7	X	***	***	***	142	144
S-37	Wood	89	400	2X2	12.7	X	***	***	E	141	141
S-38	Wood	89	400	2X2	12.7	X	***	***	E/U	144	146
S-39	Steel	65	600	1X2	12.7	X	***	***	***	88	89
S-40	Wood	65	400	1X2	12.7	X	***	***	***	86	86
S-41	Steel	90	600	1X2	15.9	X	***	***	***	136	136
S-42	Steel	90	600	1X2	15.9	X	MF	90	***	135	137
S-43	Steel	90	600	1X2	15.9	X	CFI	90	***	113	115
S-44	Steel	90	600	1X2	15.9	X	GF	90	***	133	137
S-45	Steel	90	600	2X2	15.9	X	***	***	***	202	204
S-46	Steel	90	600	1X2	12.7	X	CFI*	90	***	95	99
S-47	Steel	90	600	1X2	12.7	X	CFI*	40	***	108	110
S-48	Wood	89	400	1X1	12.7	RL*	***	***	***	37	38
S-49	Wood	89	400	2X2	12.7	RL*	***	***	***	87	87

X - Type X Gypsum12.7 mm Thick (7.83 kg/m^2) and 15.0 mm Thick (11.00 kg/m^2)
RL - Low Density Regular Gypsum Board (7.35 kg/m^2) RH - Regular Gypsum Board, no Glass Fibre in Gypsum Board (7.82 kg/m^2)
RL* - Low Density Regular Gypsum Board no Glass Fibre in Gypsum Board (7.28 kg/m^2) E - Exposed Side U - Unexposed Side
GF - Glass Fibre Insulation MF - Mineral Fibre Insulation CFI - Cellulosic Fibre Insulation(Blown Dry) CFI* - (Wet Sprayed)
*** - Null Value

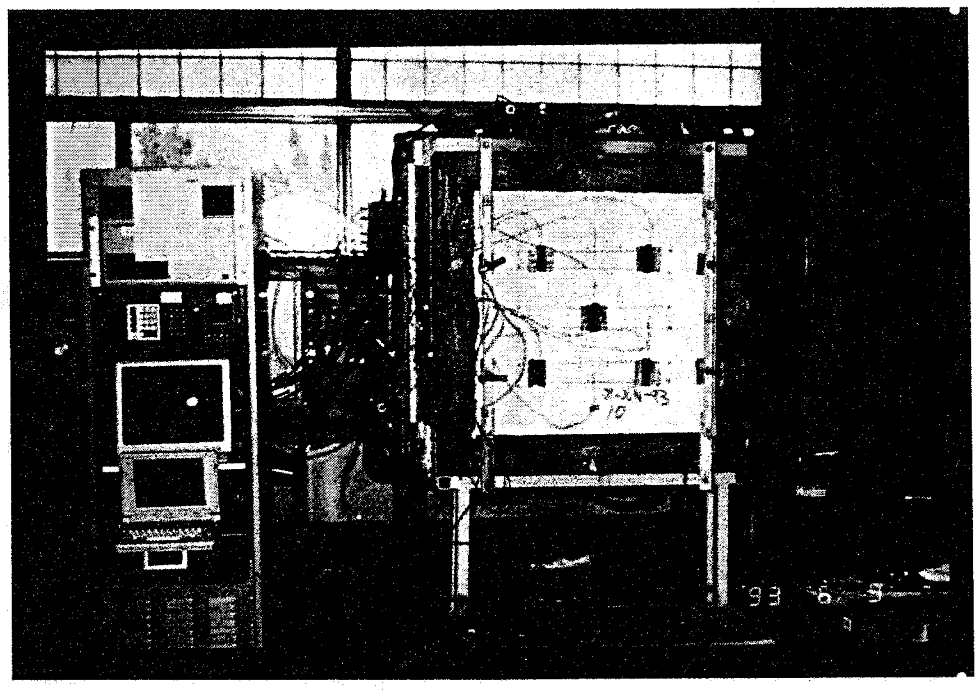


Figure 1. Small-Scale Test Assembly Furnace

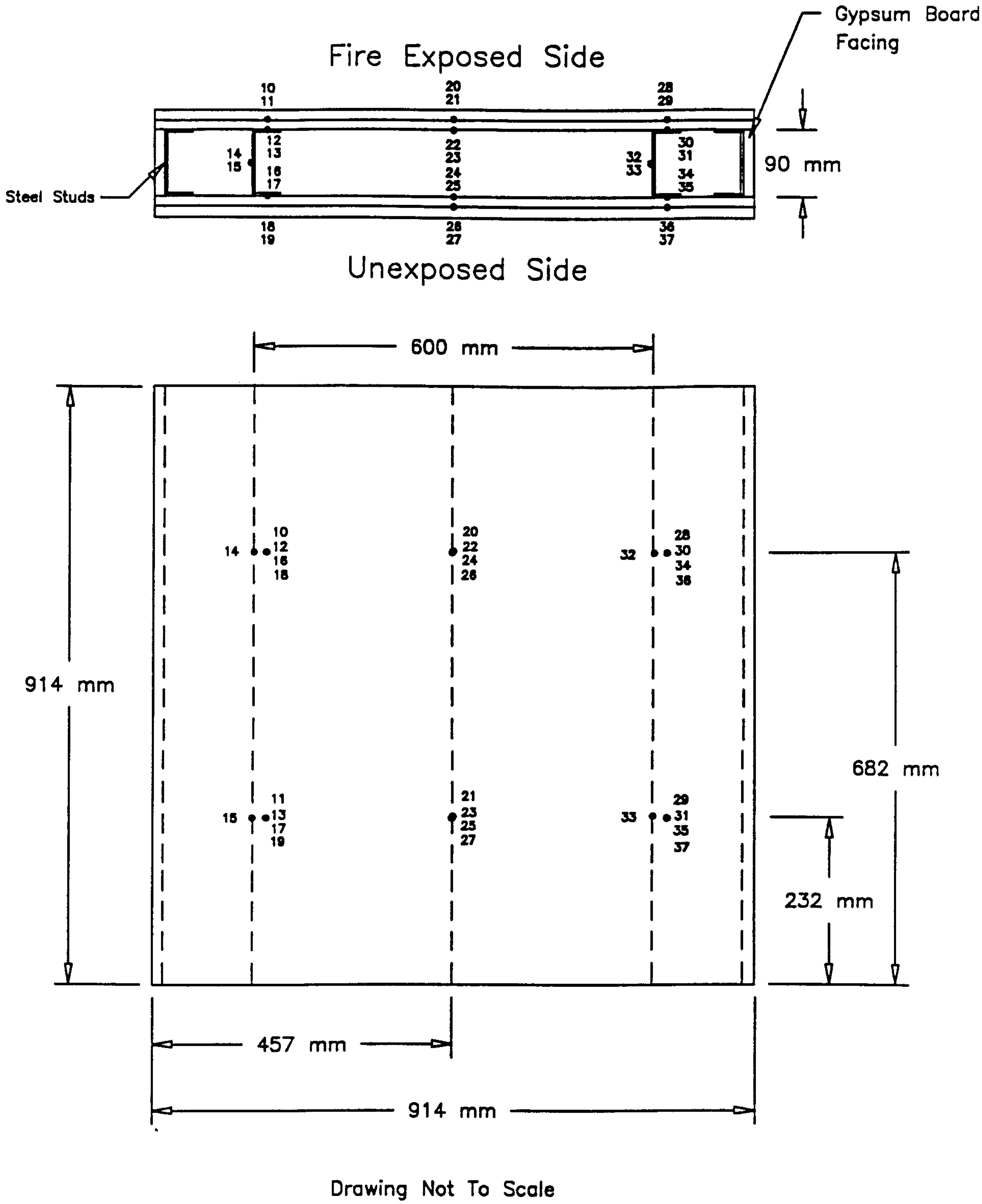


Figure 2. Thermocouple Locations in Small-Scale Test S-01B and S-01C

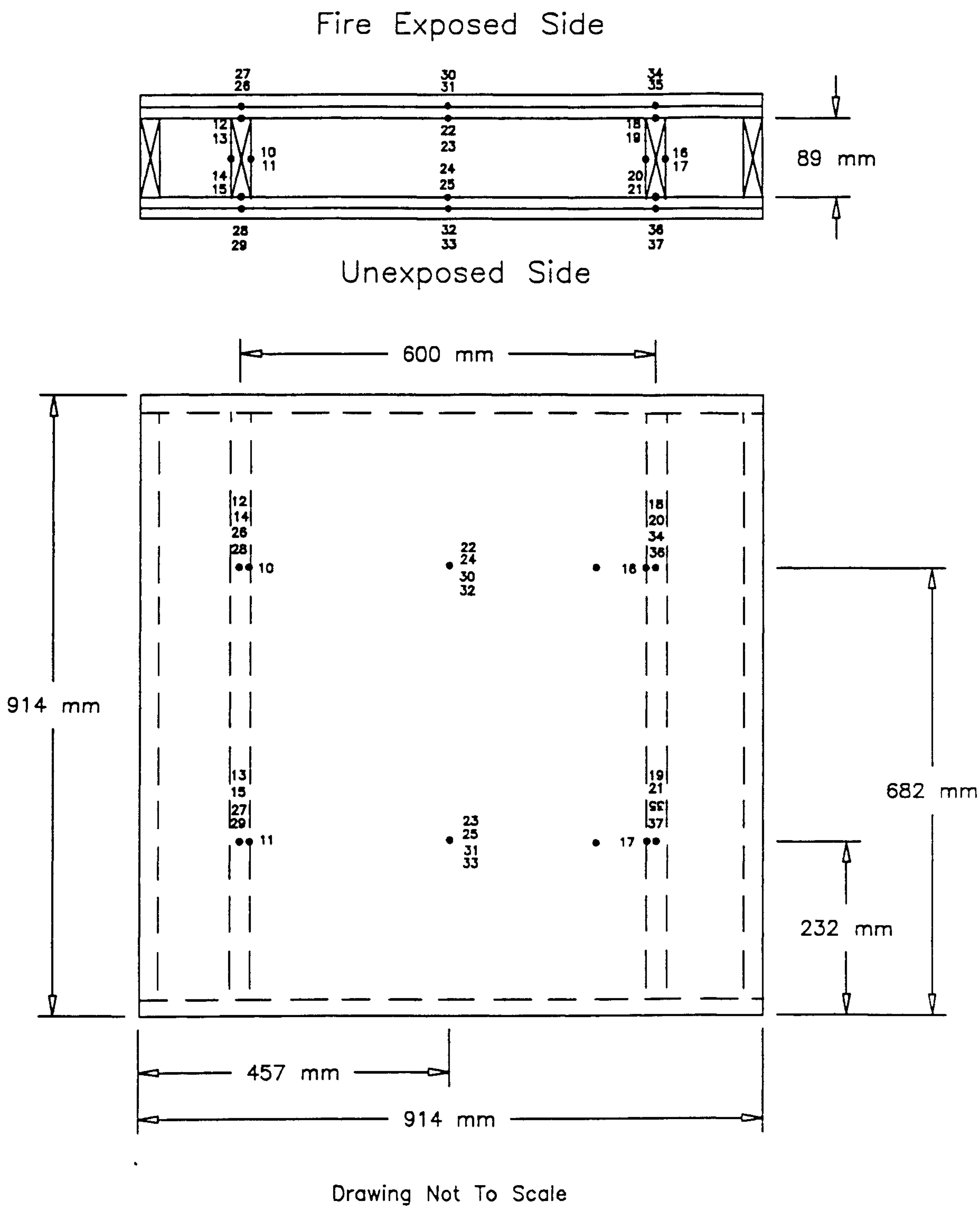


Figure 3. Thermocouple Locations in Small-Scale Test S-02

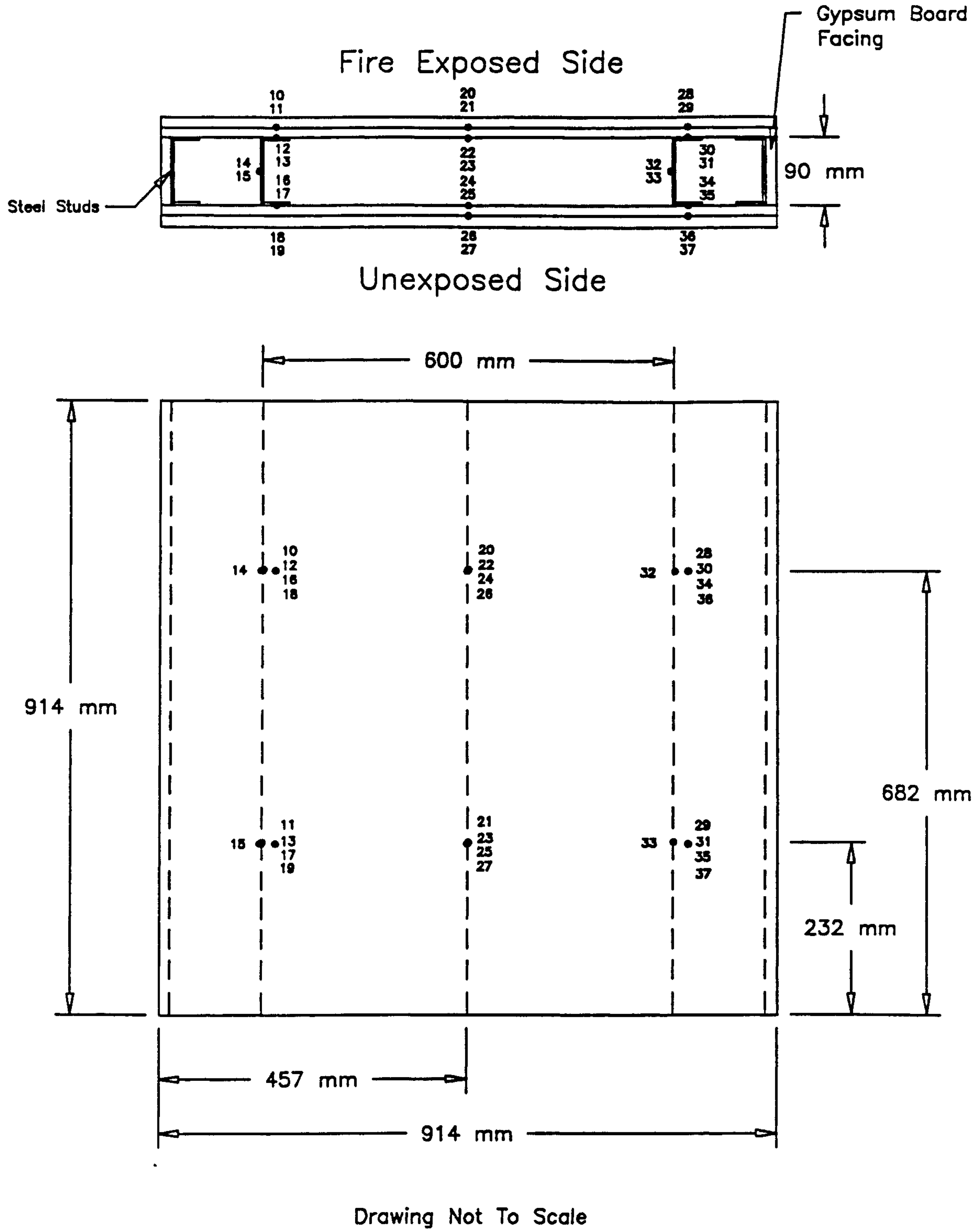


Figure 4. Thermocouple Locations in Small-Scale Test S-03

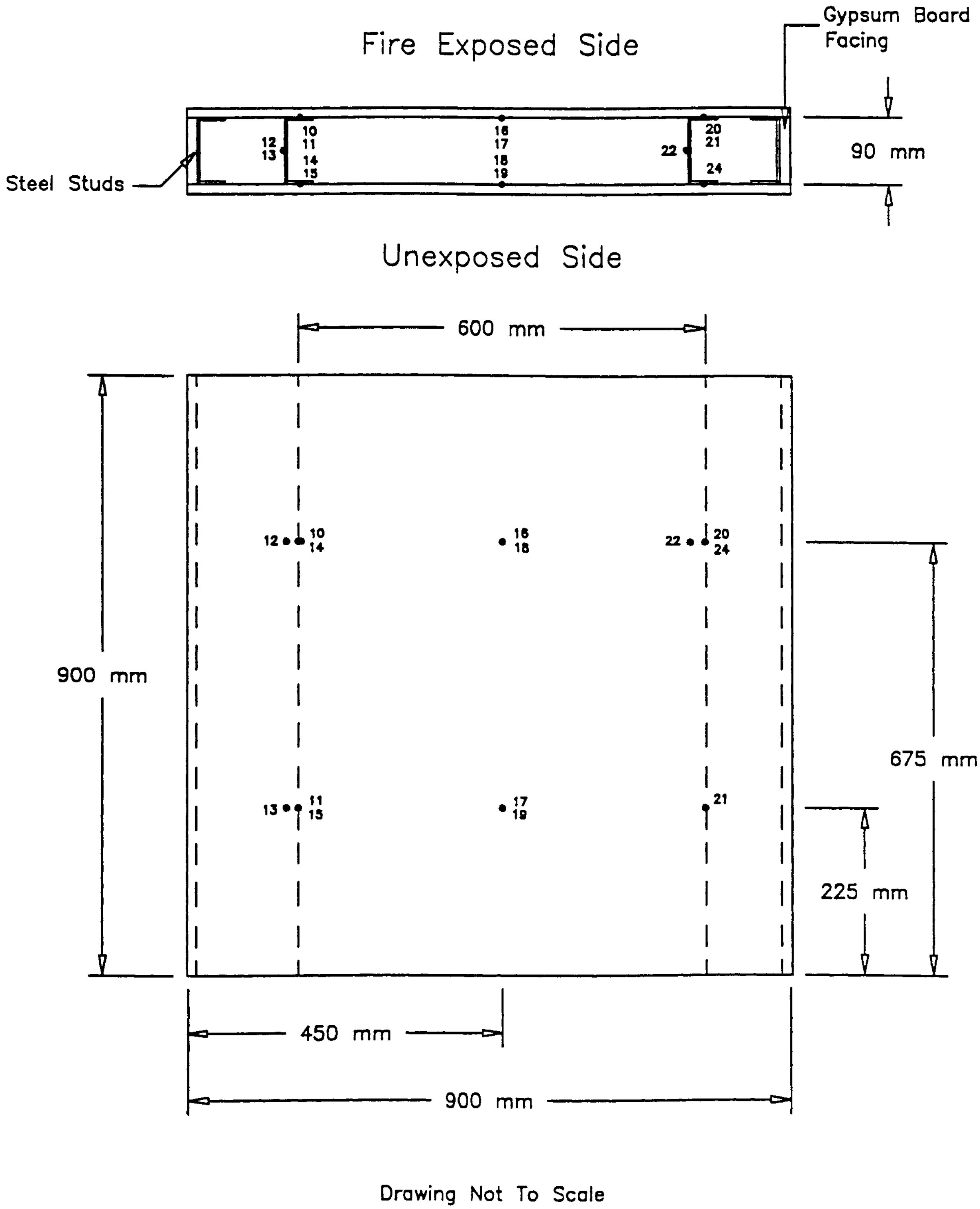


Figure 5. Thermocouple Locations in Small-Scale Test S-04

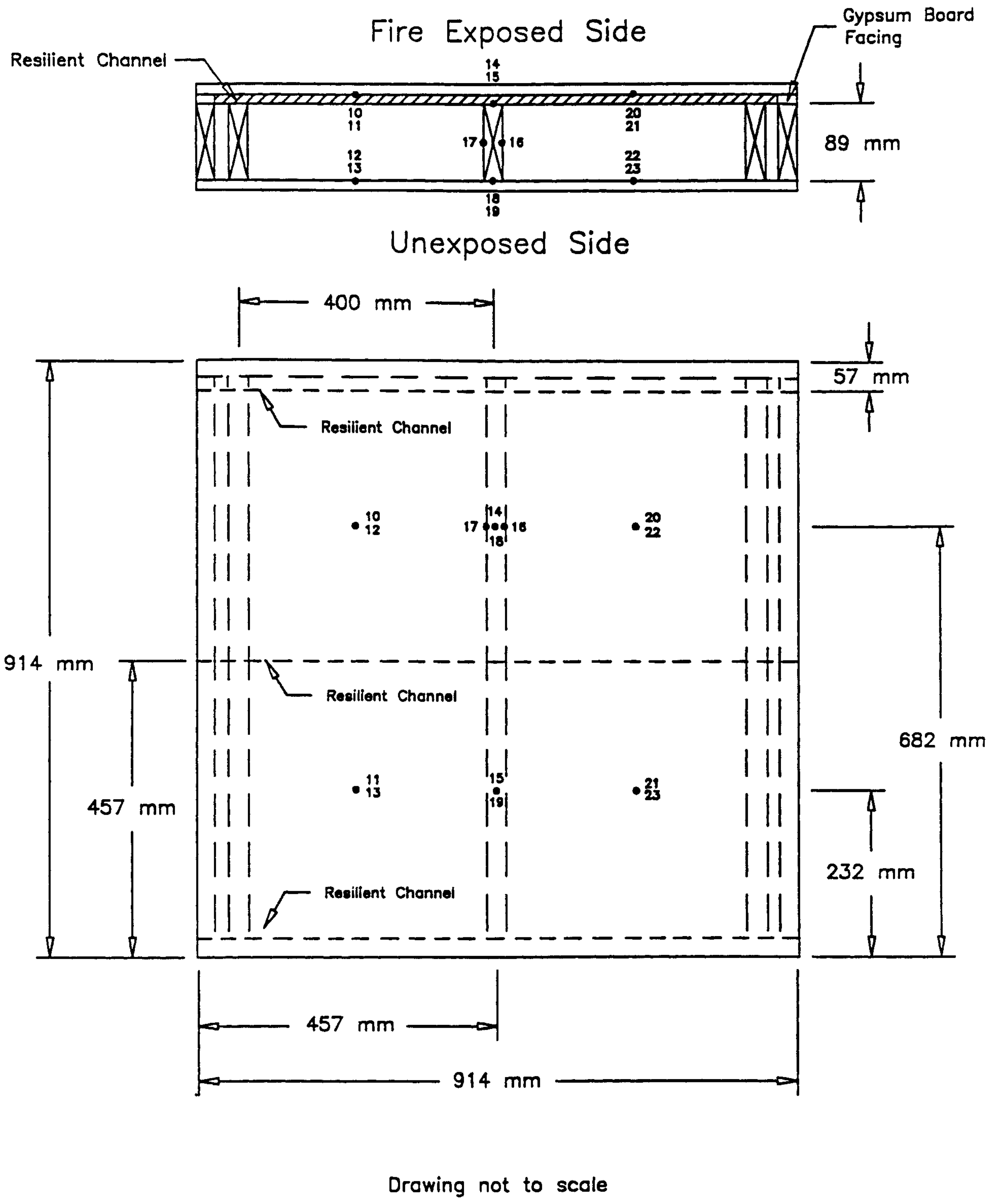


Figure 6. Thermocouple Locations in Small-Scale Test S-05

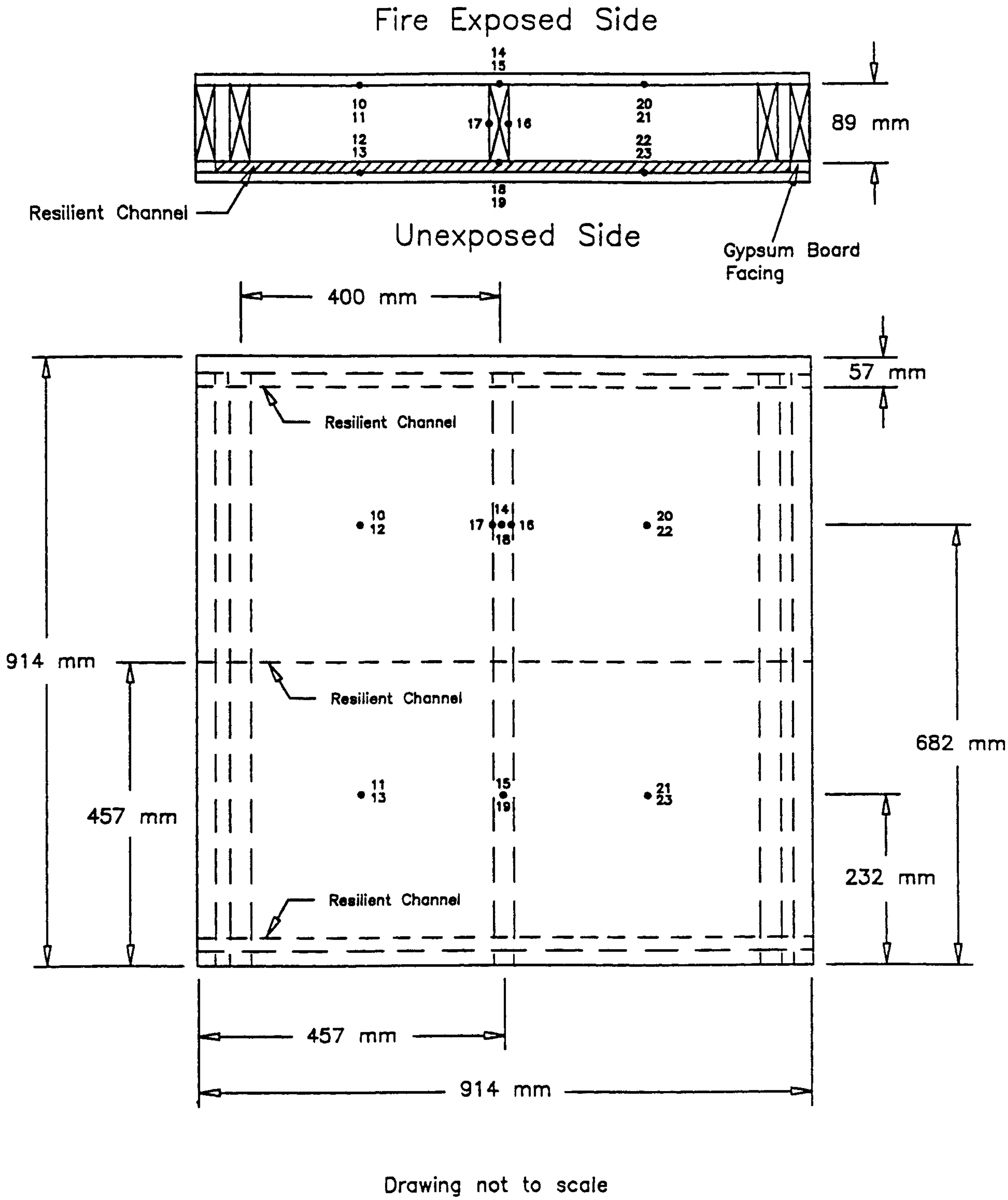


Figure 7. Thermocouple Locations in Small-Scale Test S-06

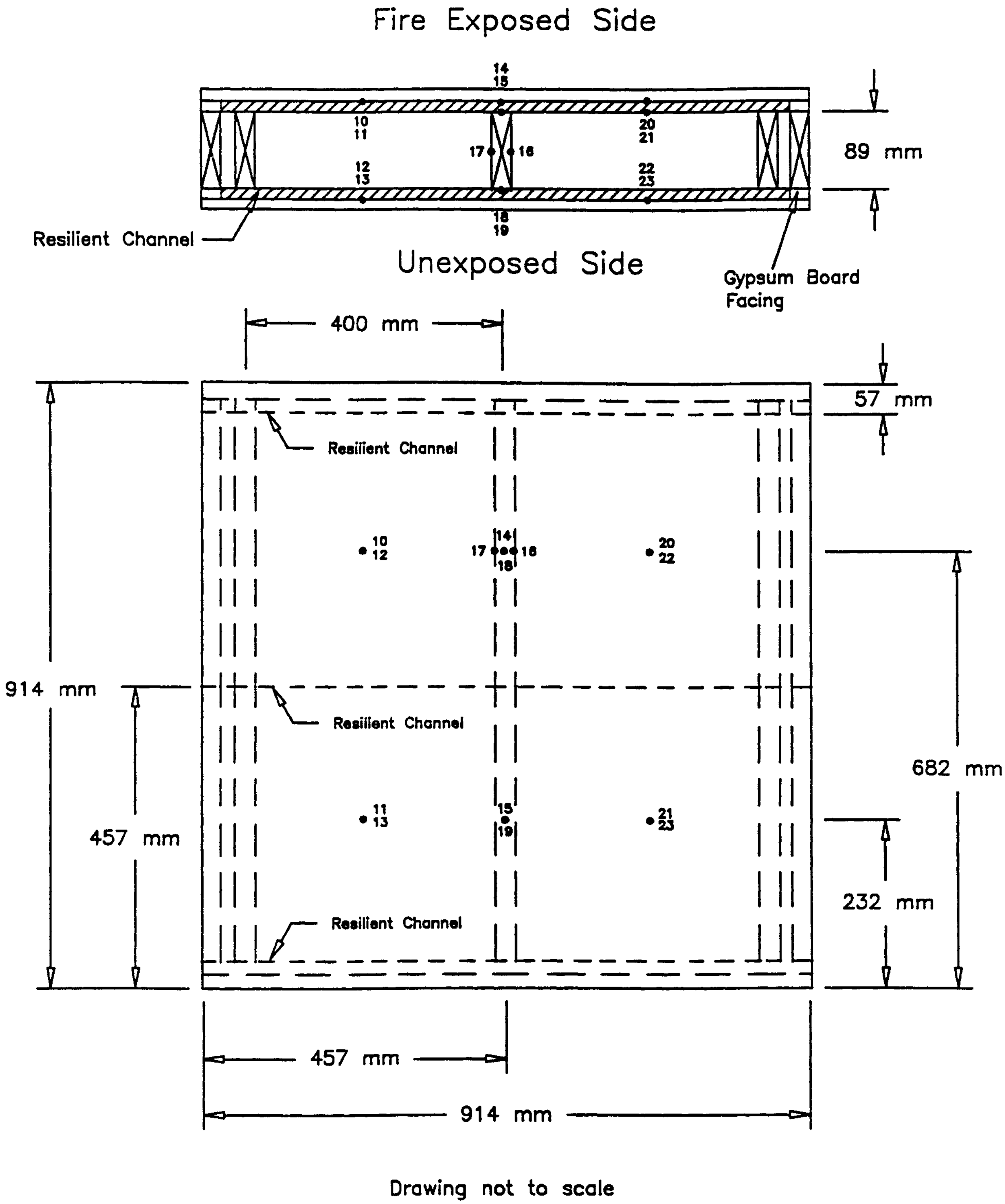


Figure 8. Thermocouple Locations in Small-Scale Test S-07

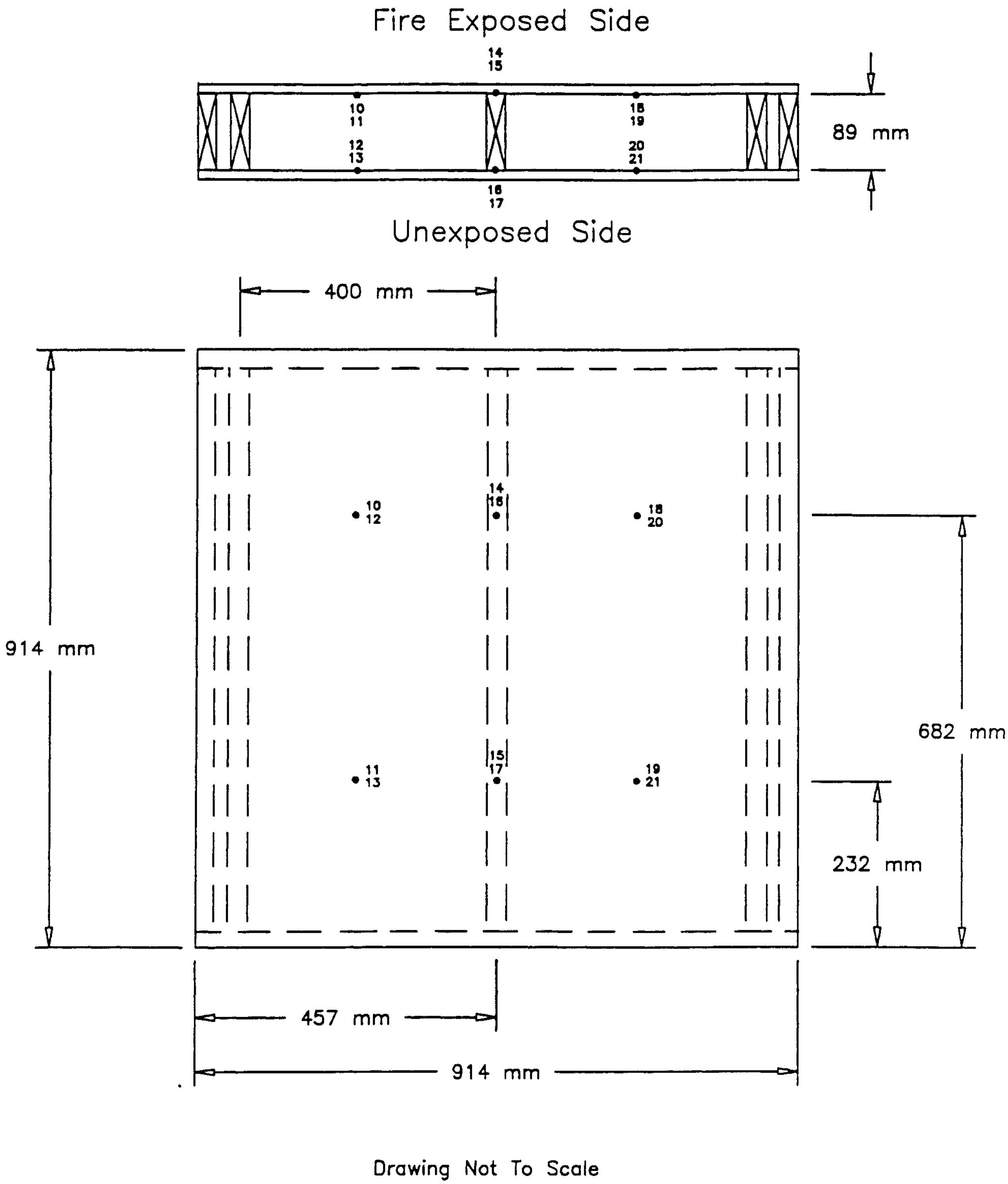


Figure 9. Thermocouple Locations in Small-Scale Test S-08

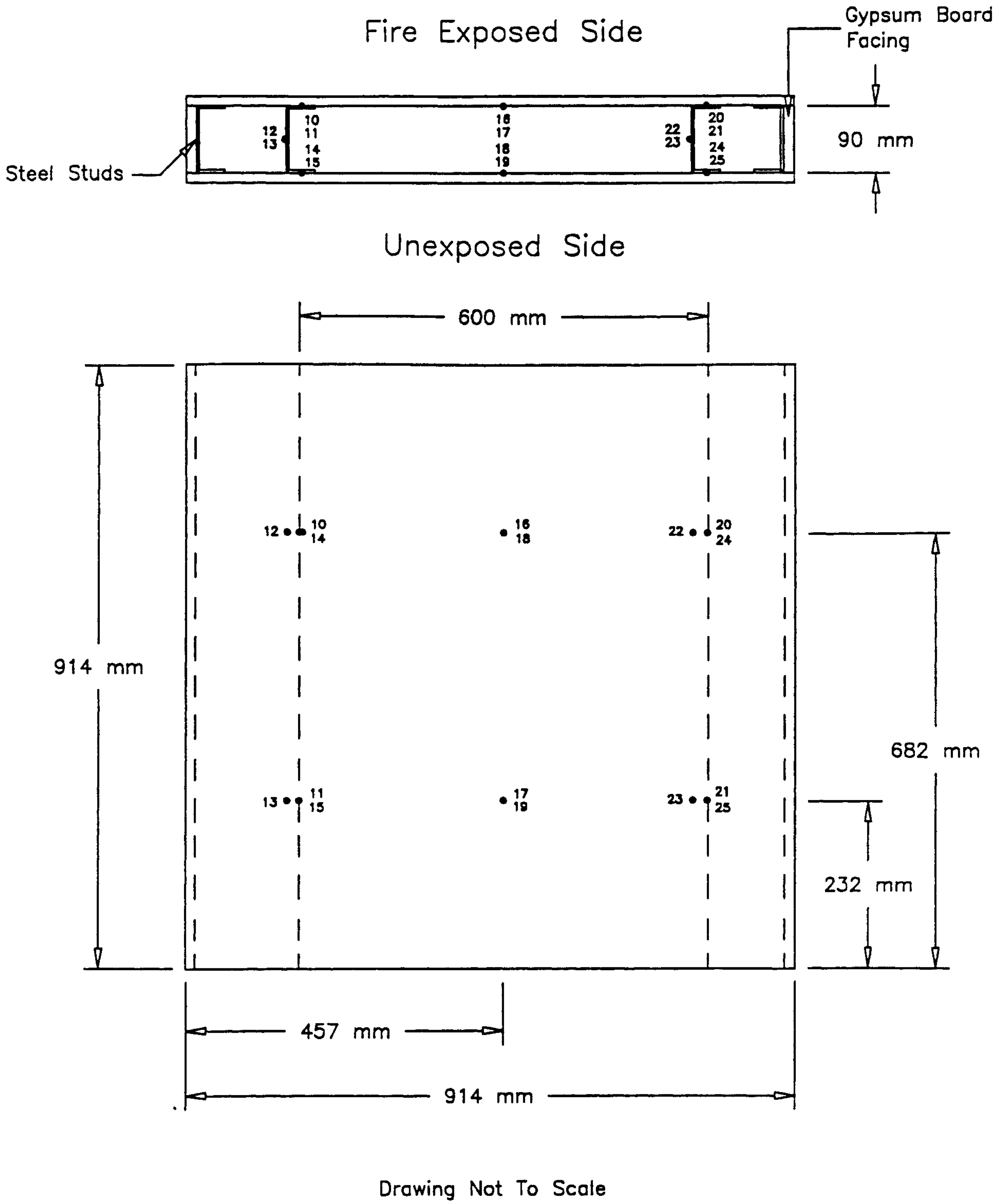


Figure 10. Thermocouple Locations in Small-Scale Test S-09

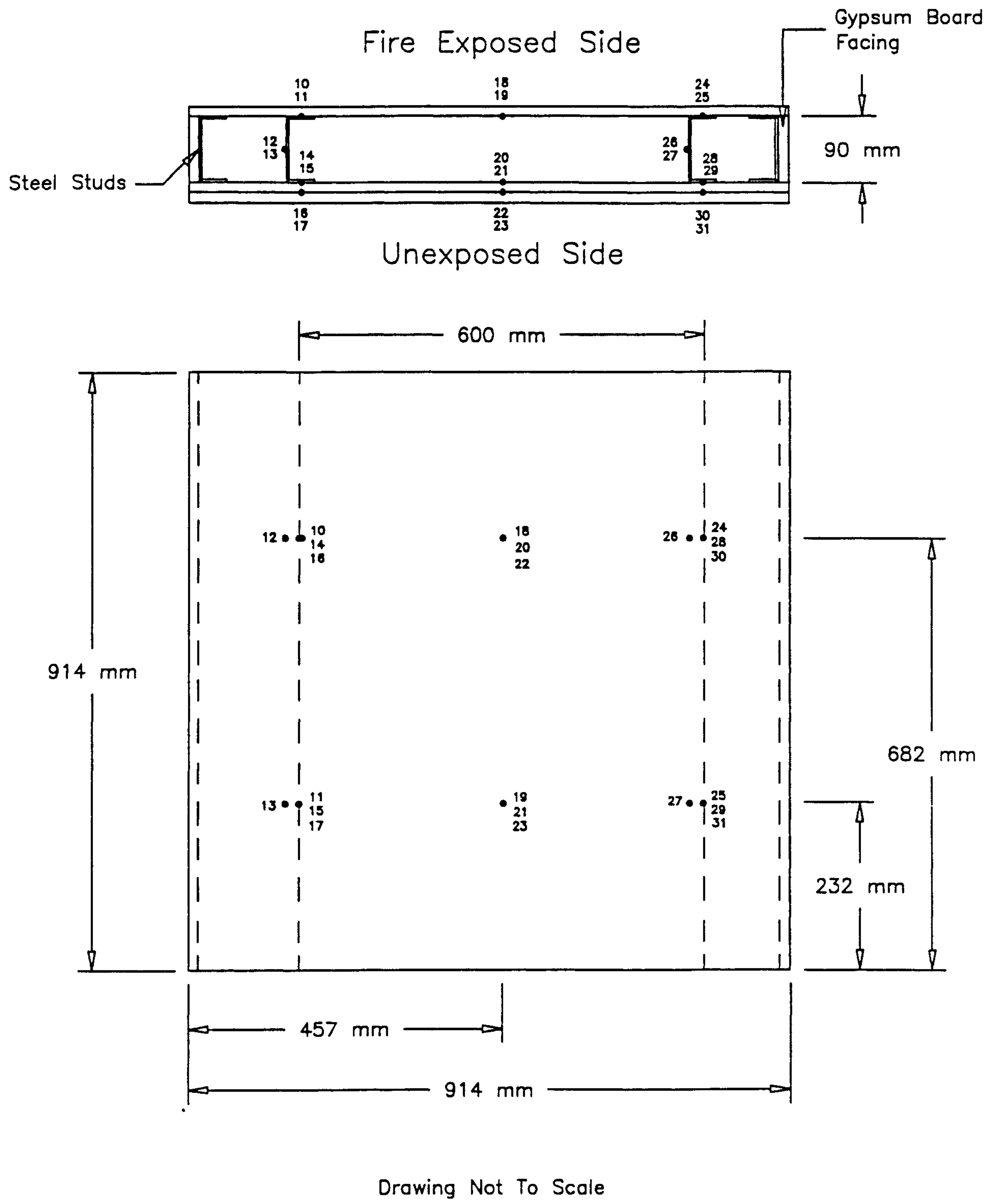


Figure 11. Thermocouple Locations in Small-Scale Test S-10

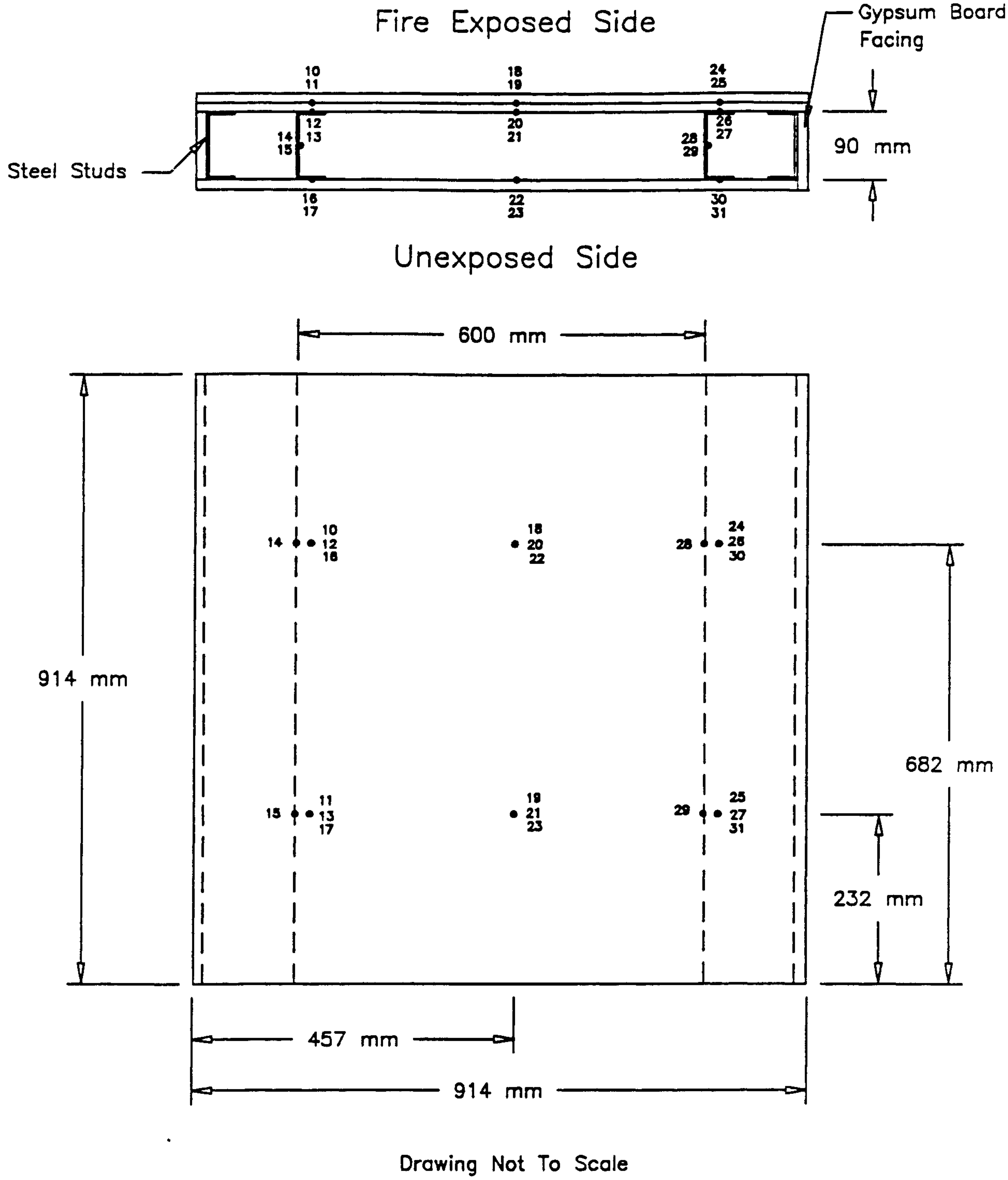


Figure 12. Thermocouple Locations in Small-Scale Test S-11

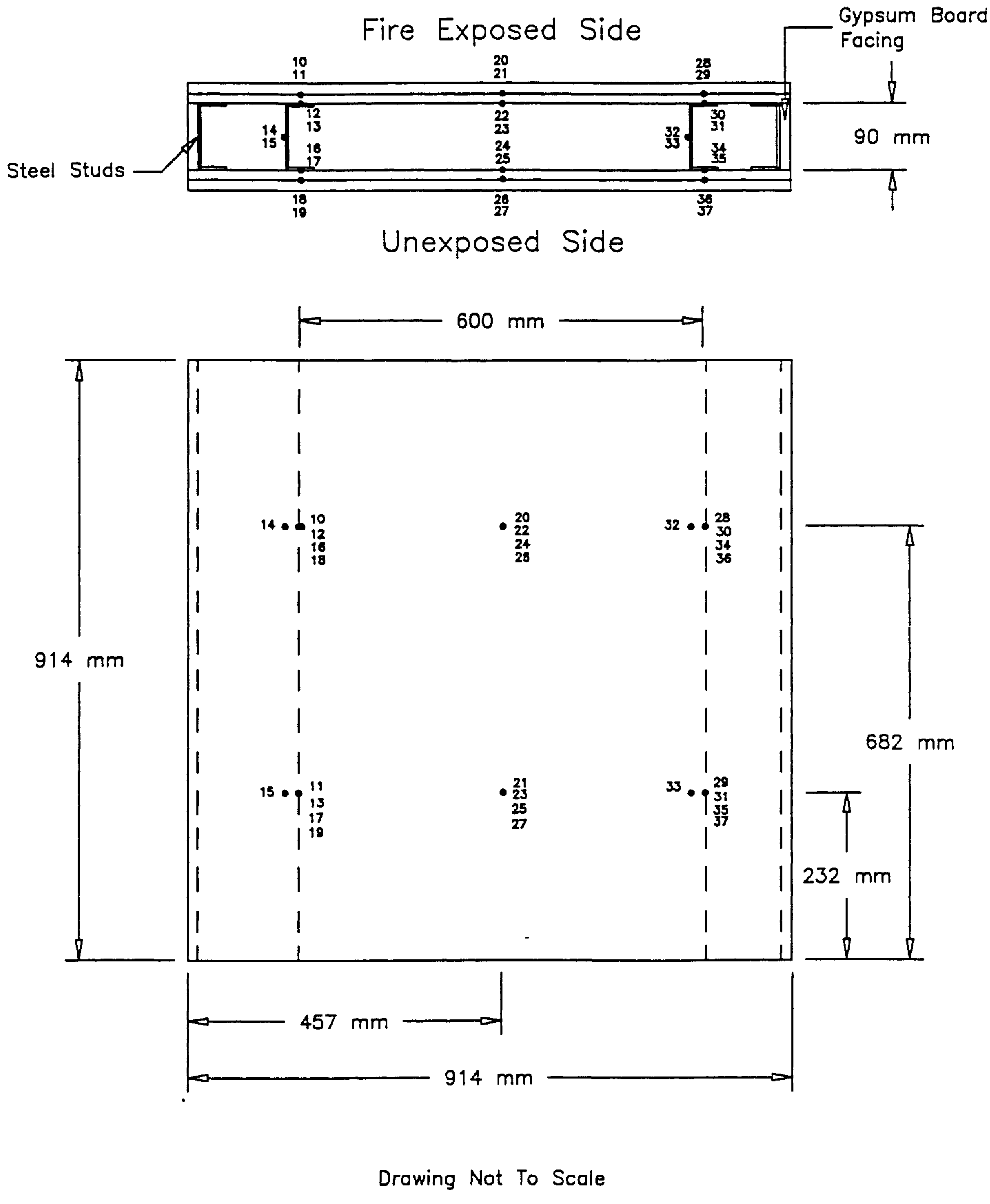


Figure 13. Thermocouple Locations in Small-Scale Test S-12

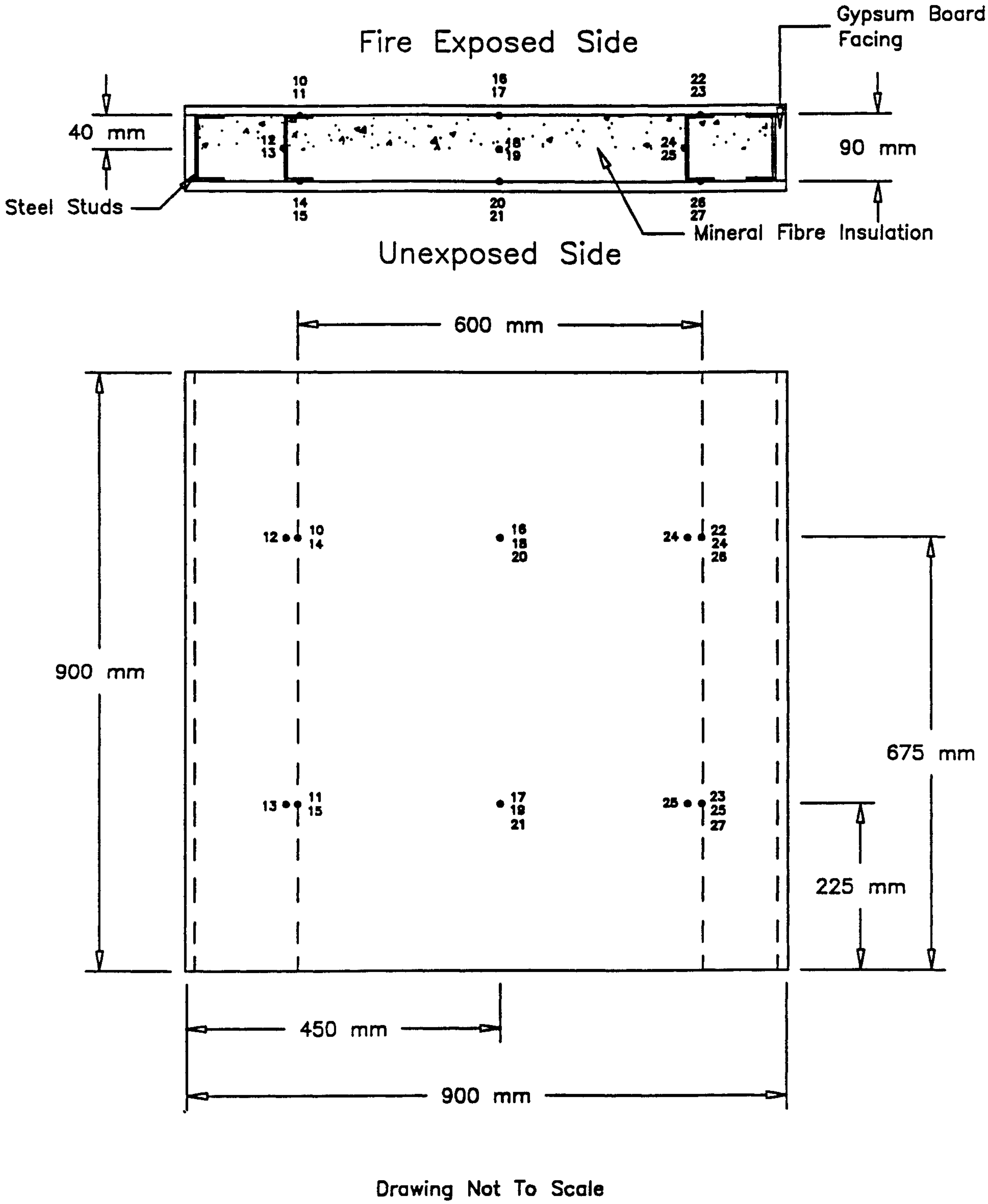


Figure 14. Thermocouple Locations in Small-Scale Test S-14

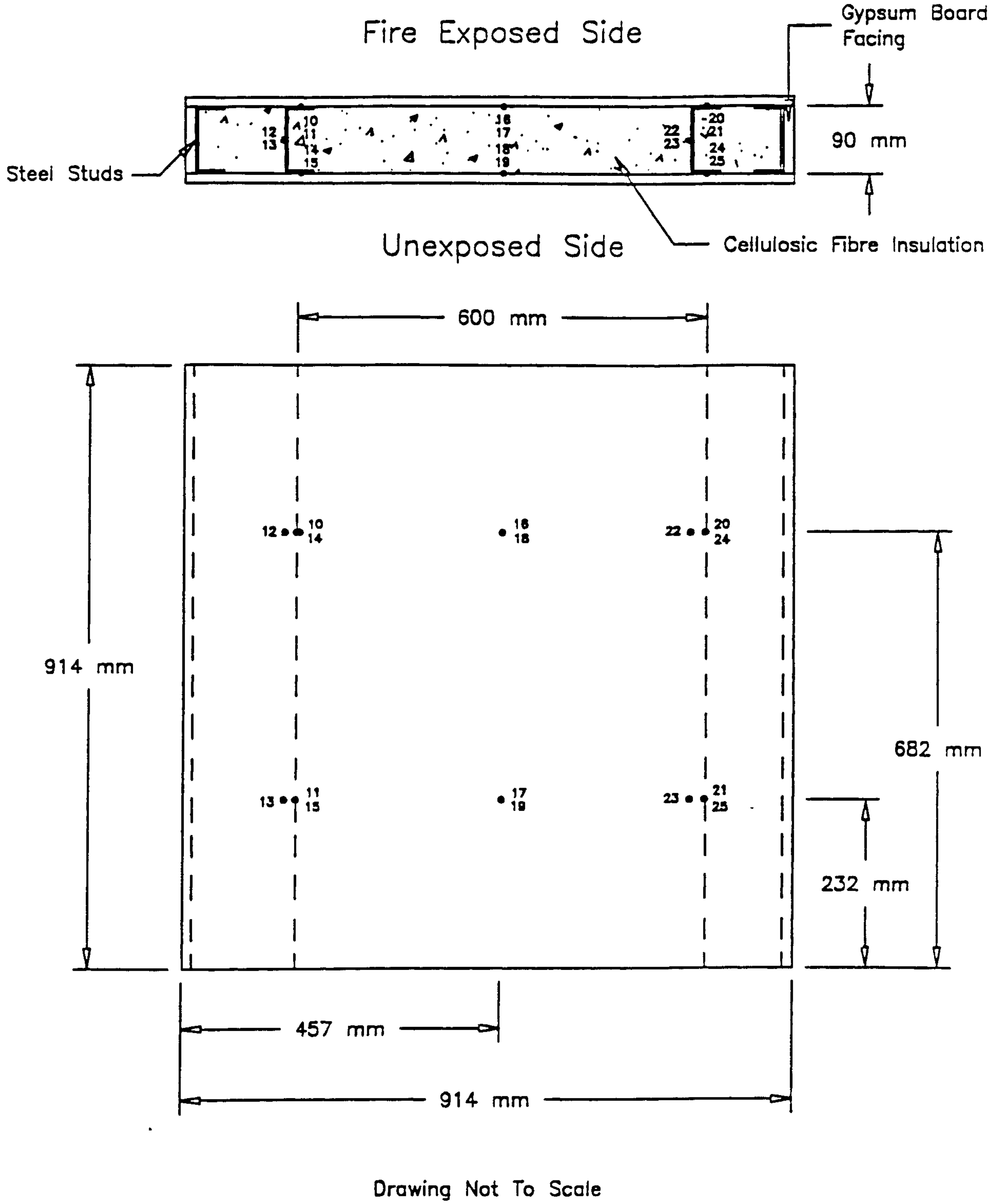


Figure 15. Thermocouple Locations in Small-Scale Test S-15

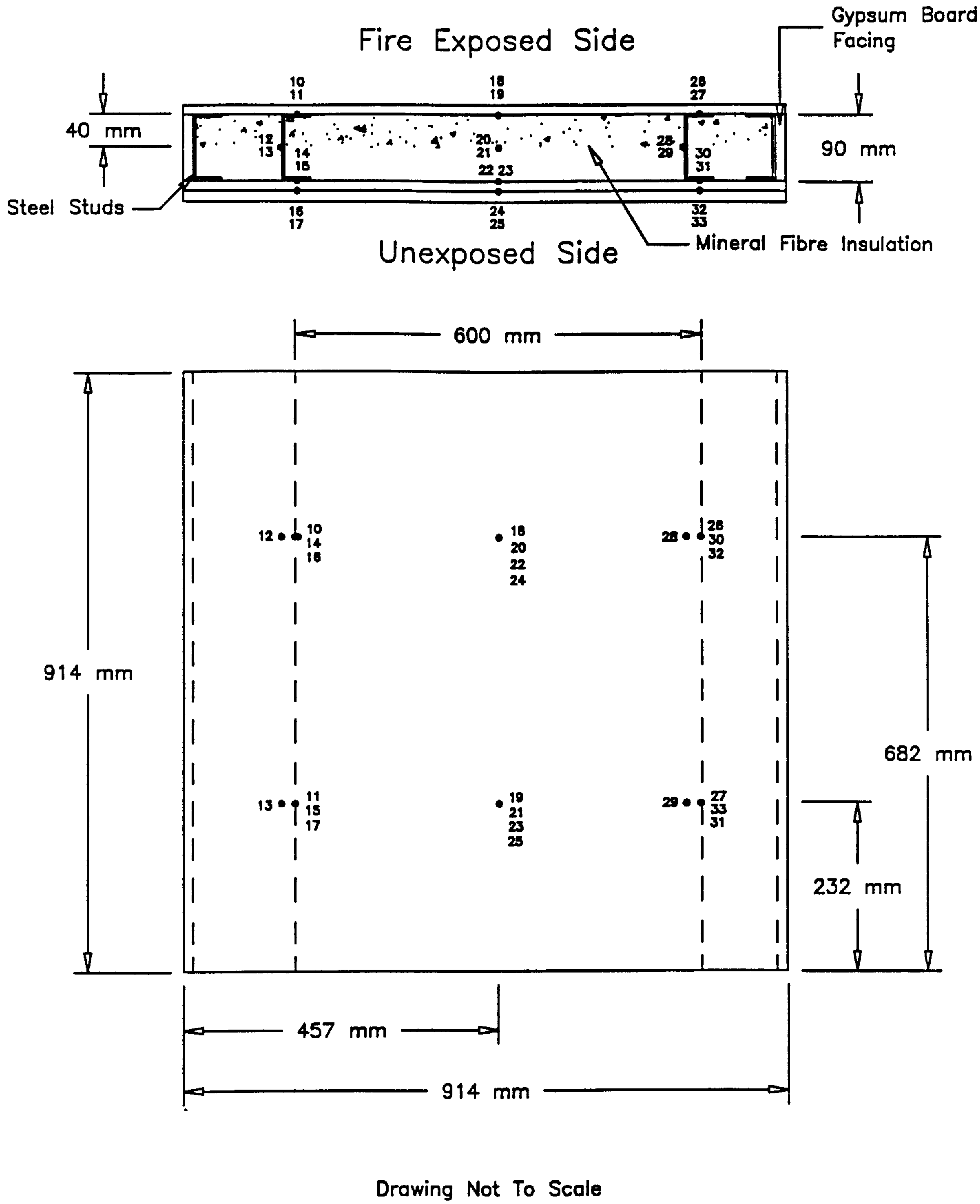


Figure 16. Thermocouple Locations in Small-Scale Test S-17

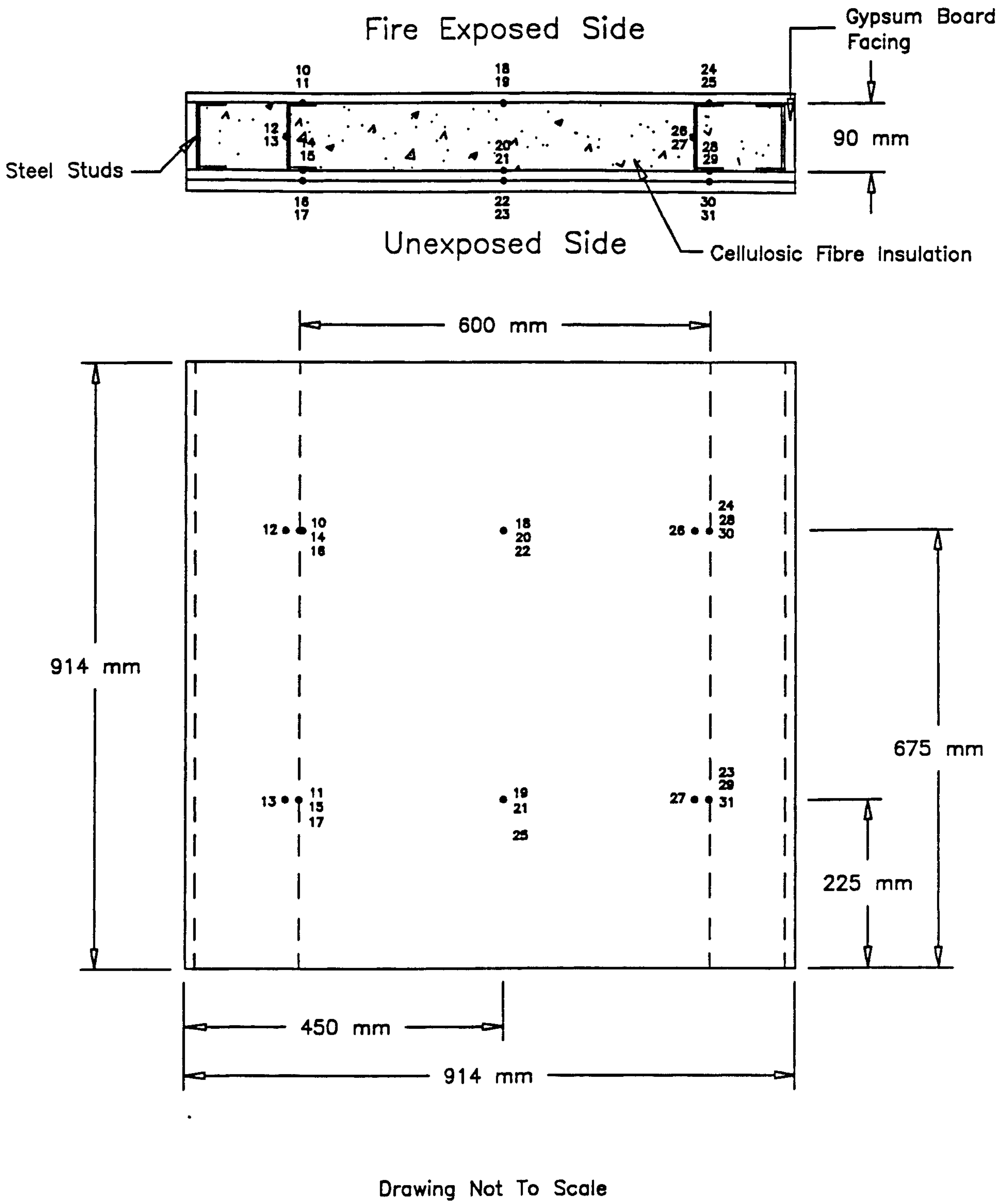


Figure 17. Thermocouple Locations in Small-Scale Test S-18

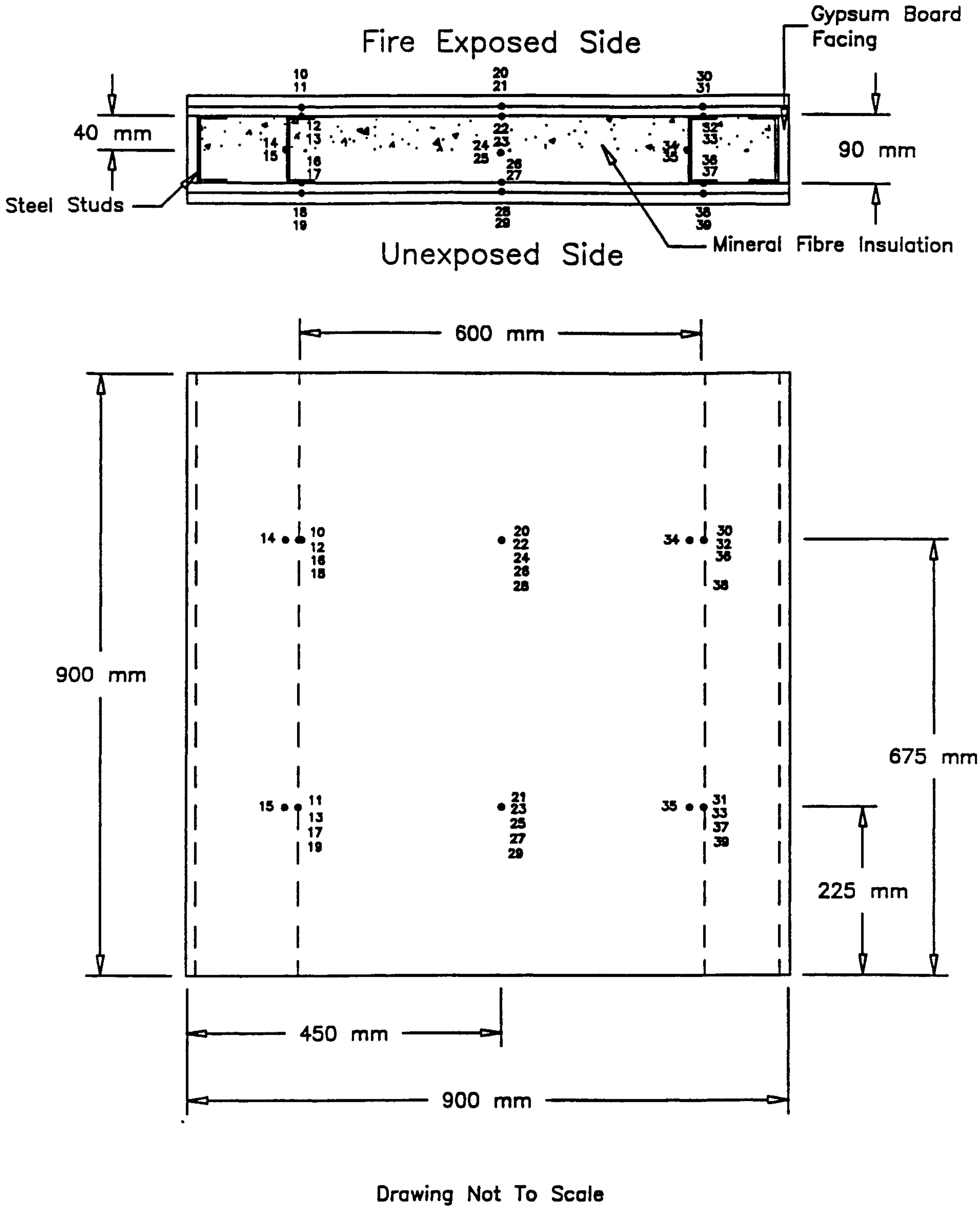


Figure 18. Thermocouple Locations in Small-Scale Test S-20

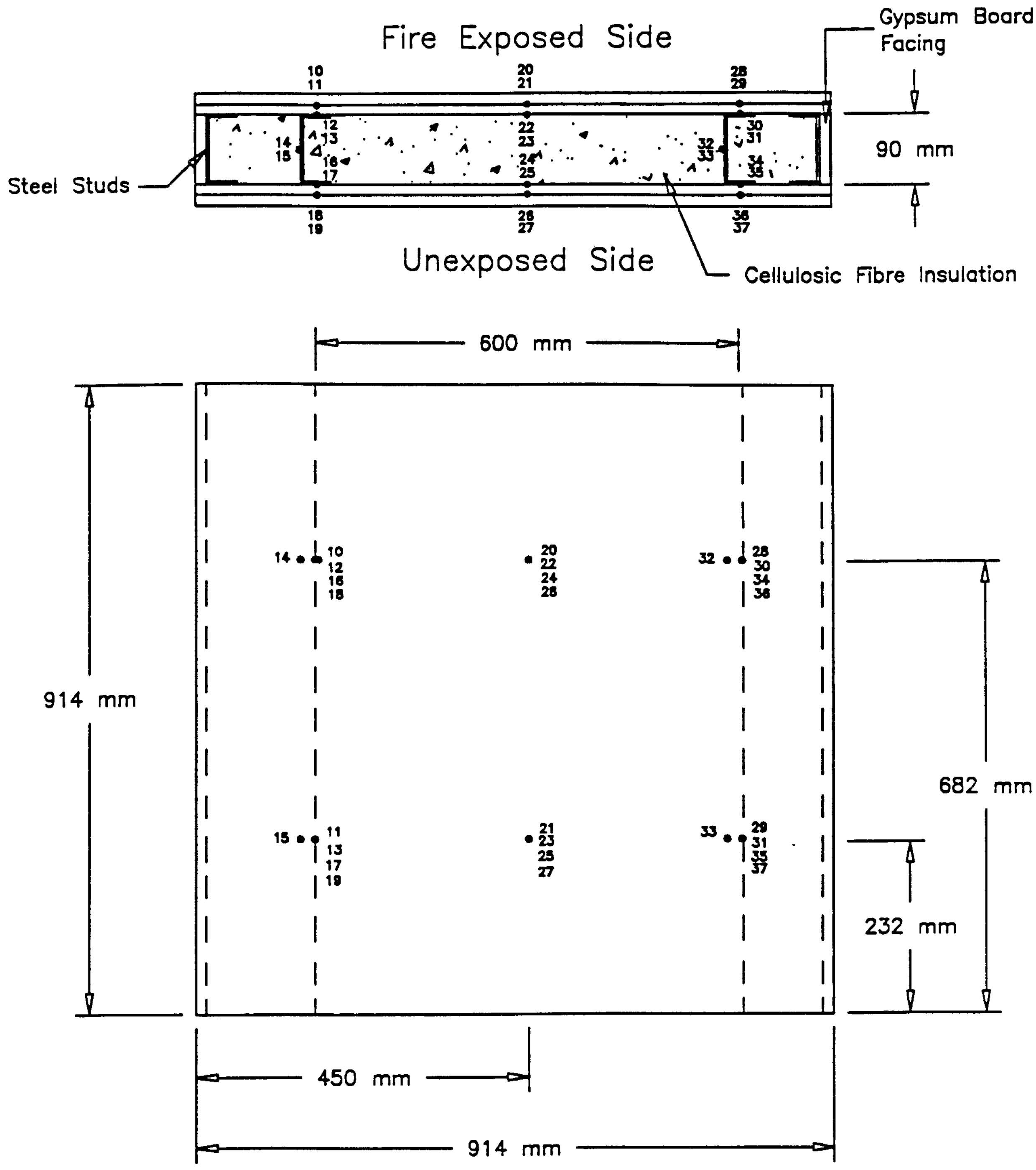


Figure 19. Thermocouple Locations in Small-Scale Test S-21

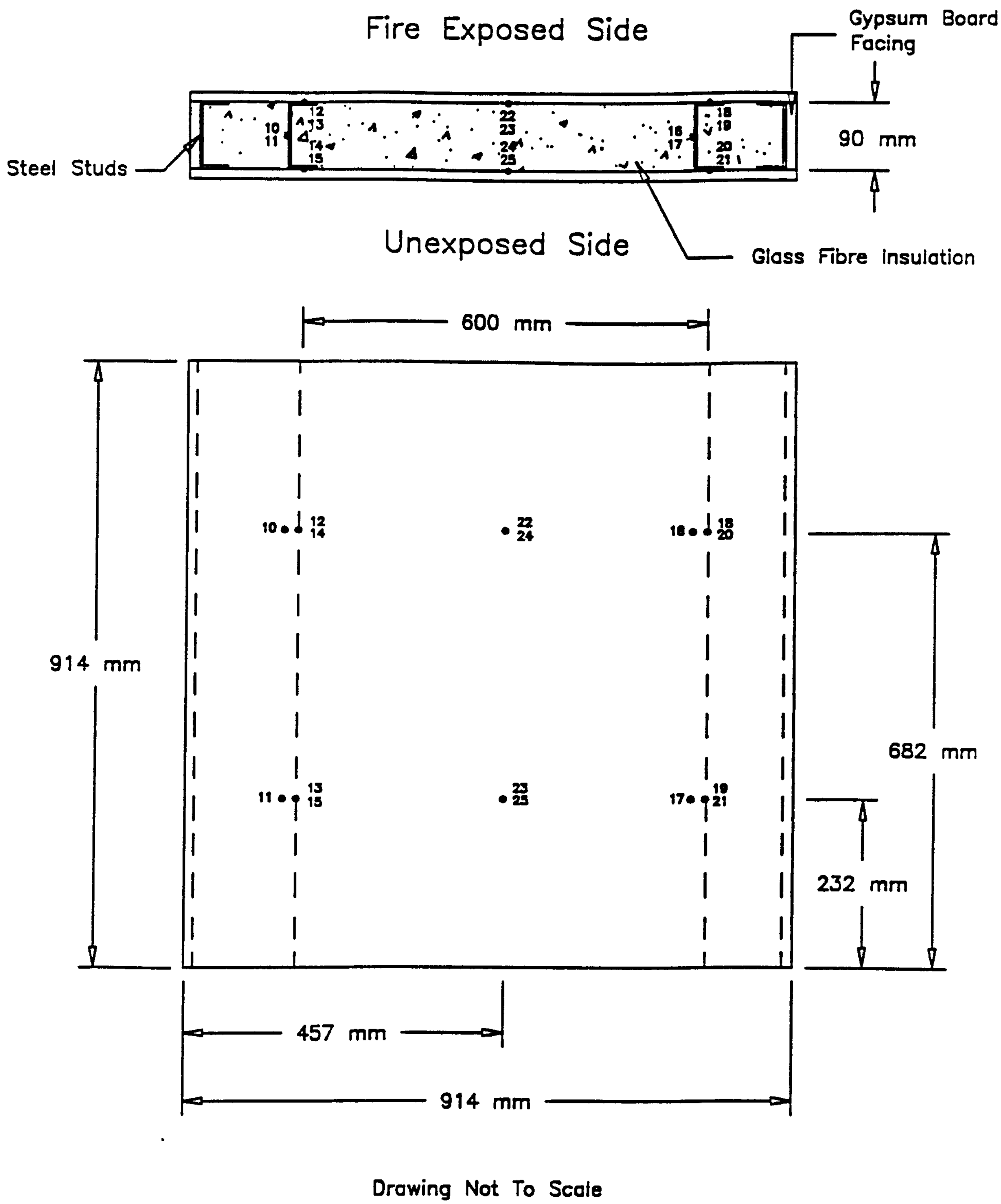


Figure 20. Thermocouple Locations in Small-Scale Test S-22

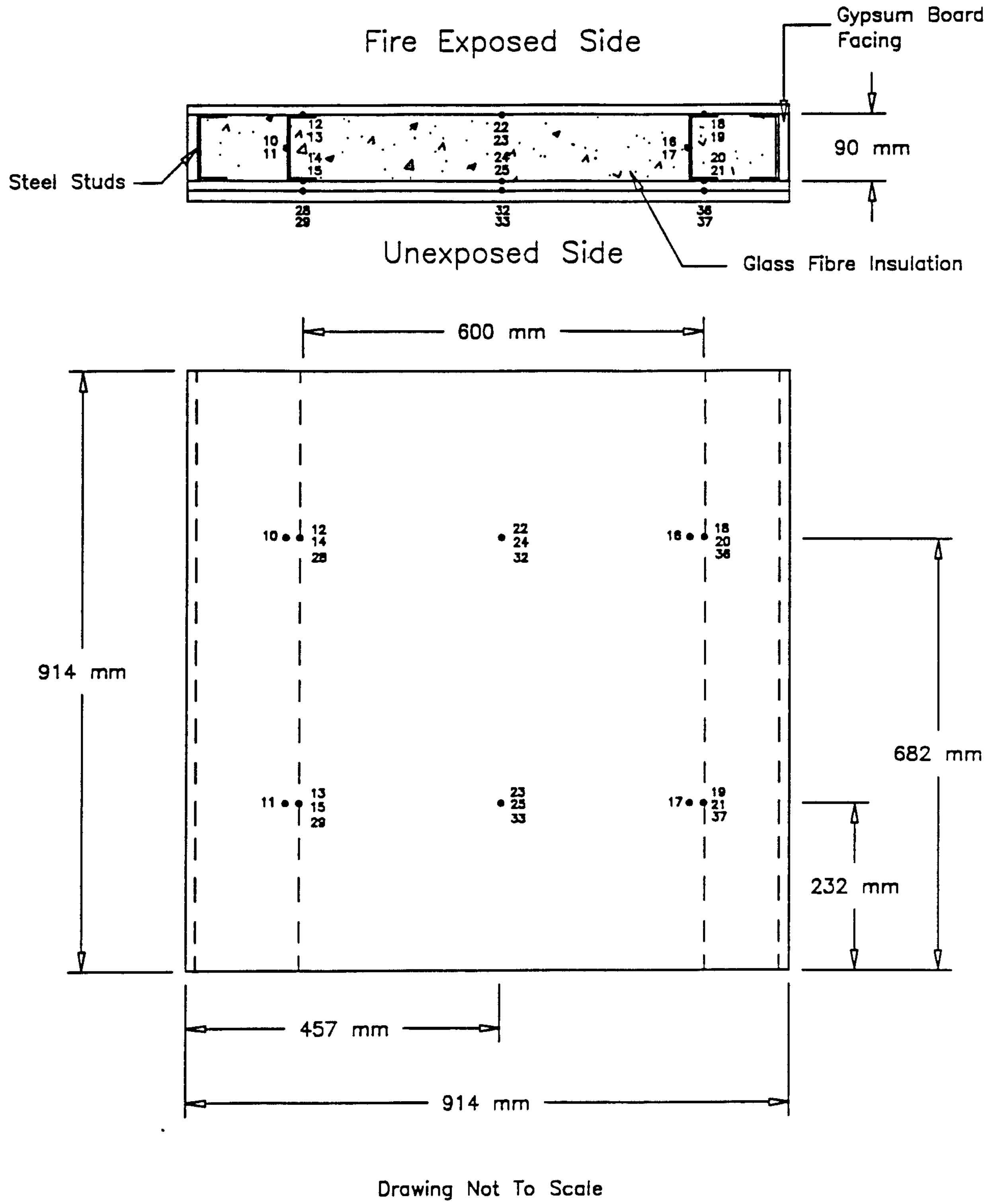


Figure 21. Thermocouple Locations in Small-Scale Test S-23

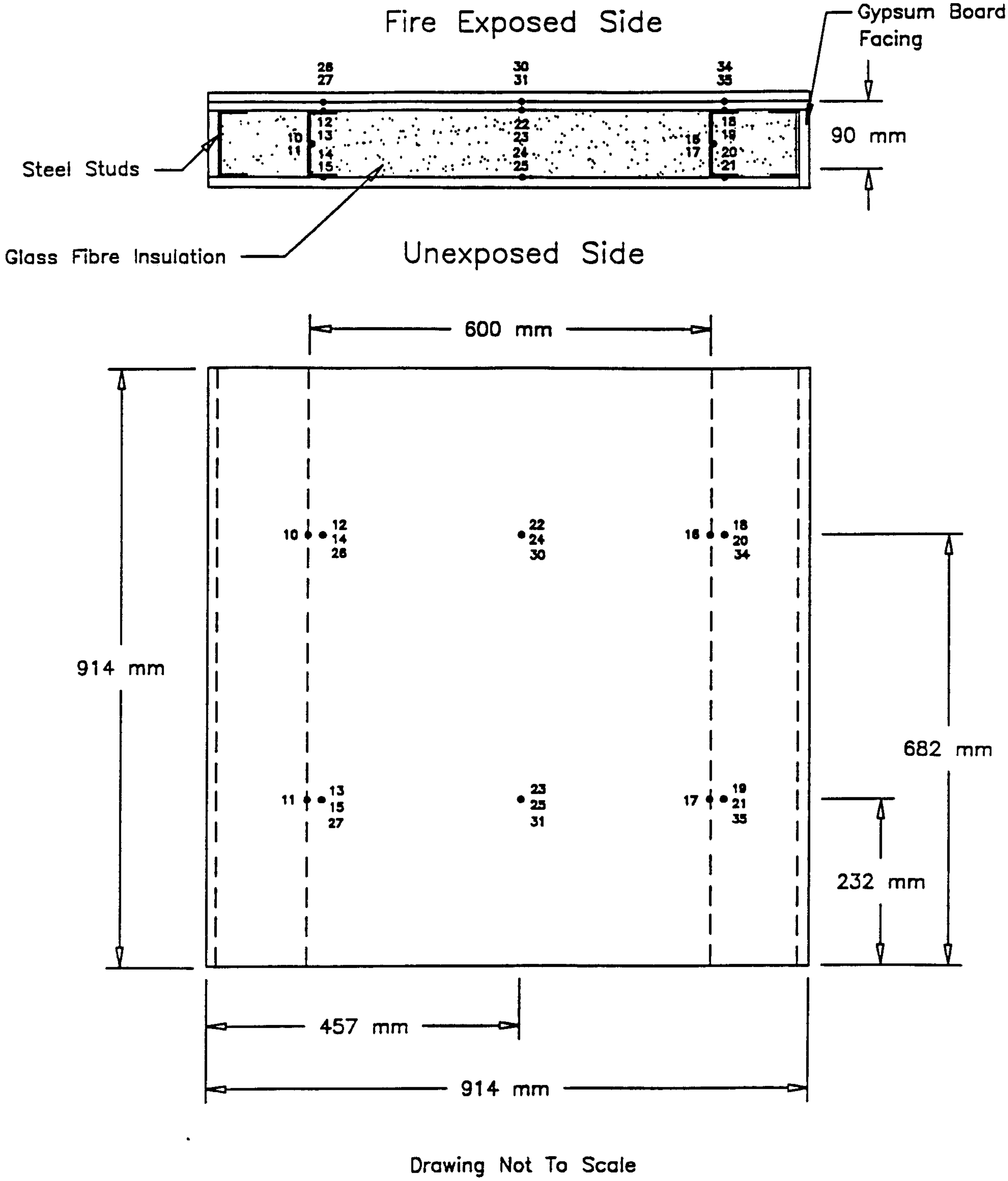


Figure 22. Thermocouple Locations in Small-Scale Test S-24

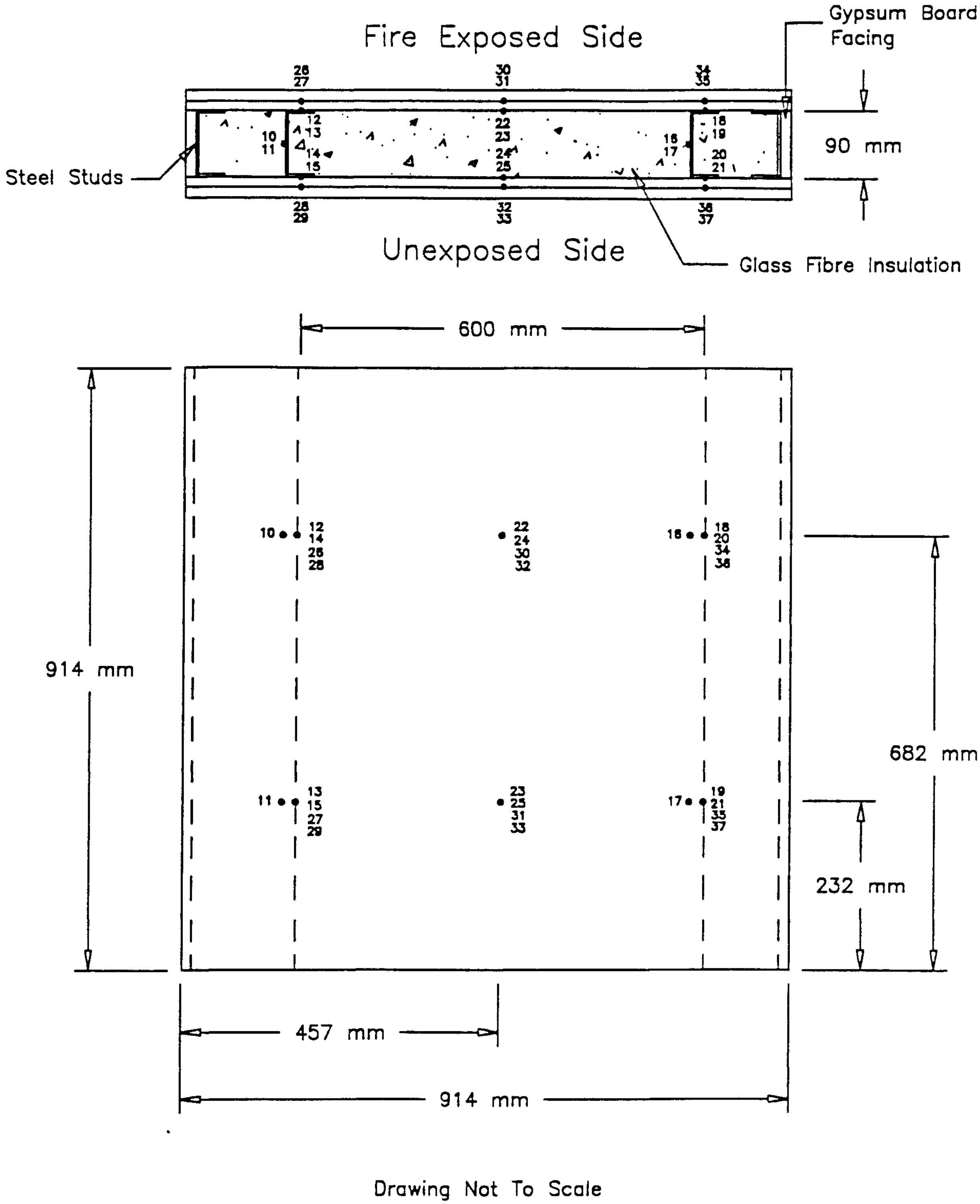


Figure 23. Thermocouple Locations in Small-Scale Test S-25

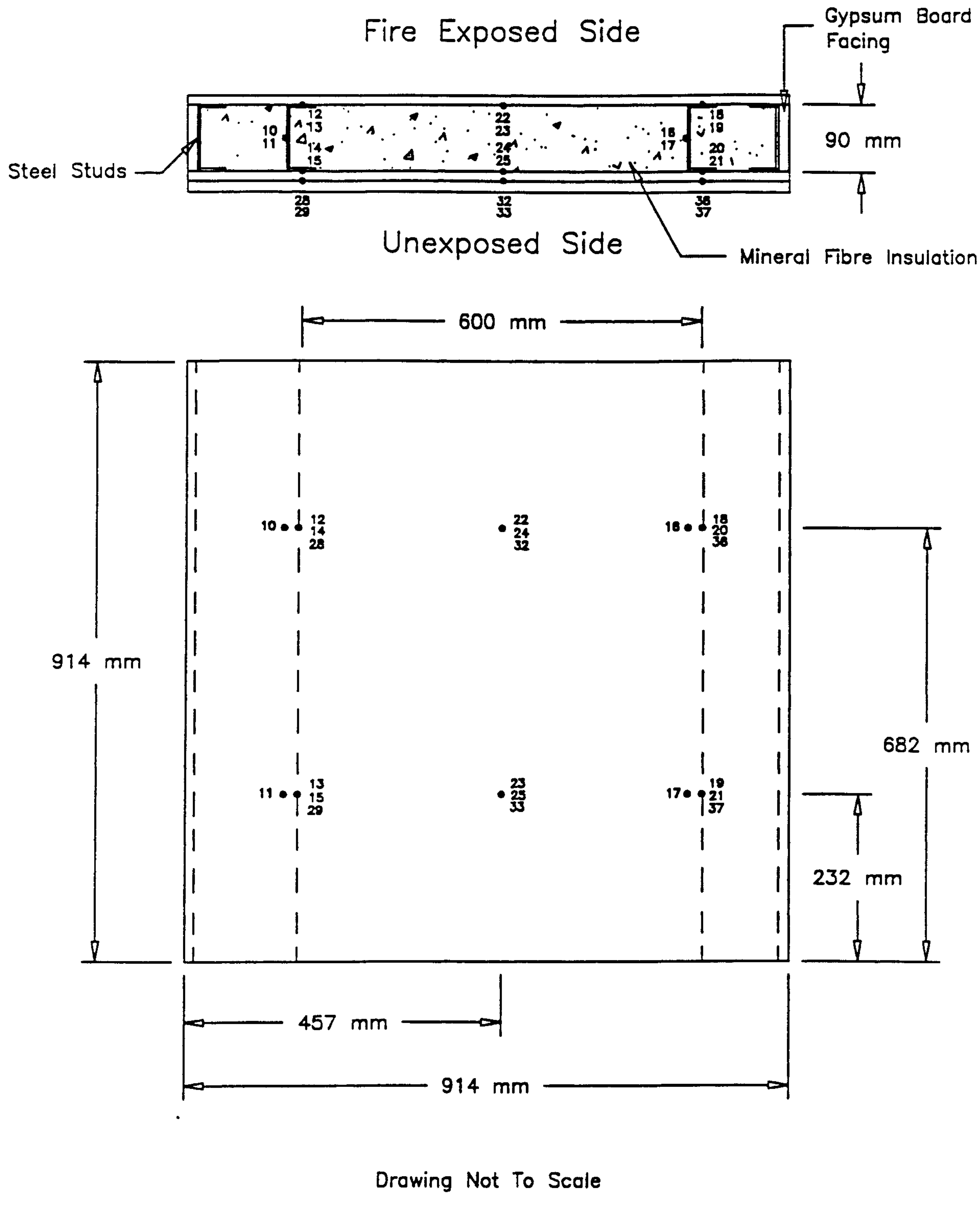


Figure 24. Thermocouple Locations in Small-Scale Test S-26

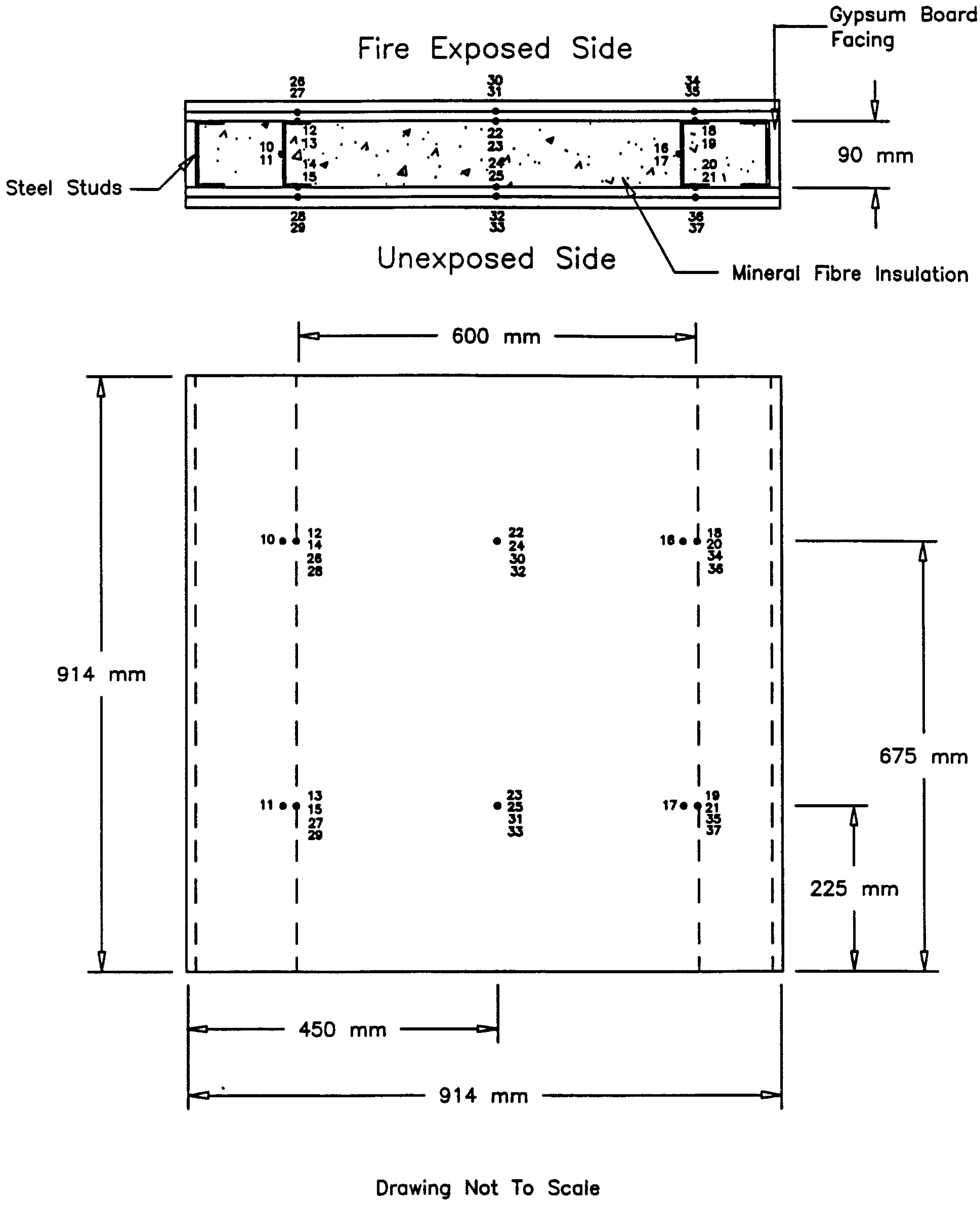


Figure 25. Thermocouple Locations in Small-Scale Test S-27

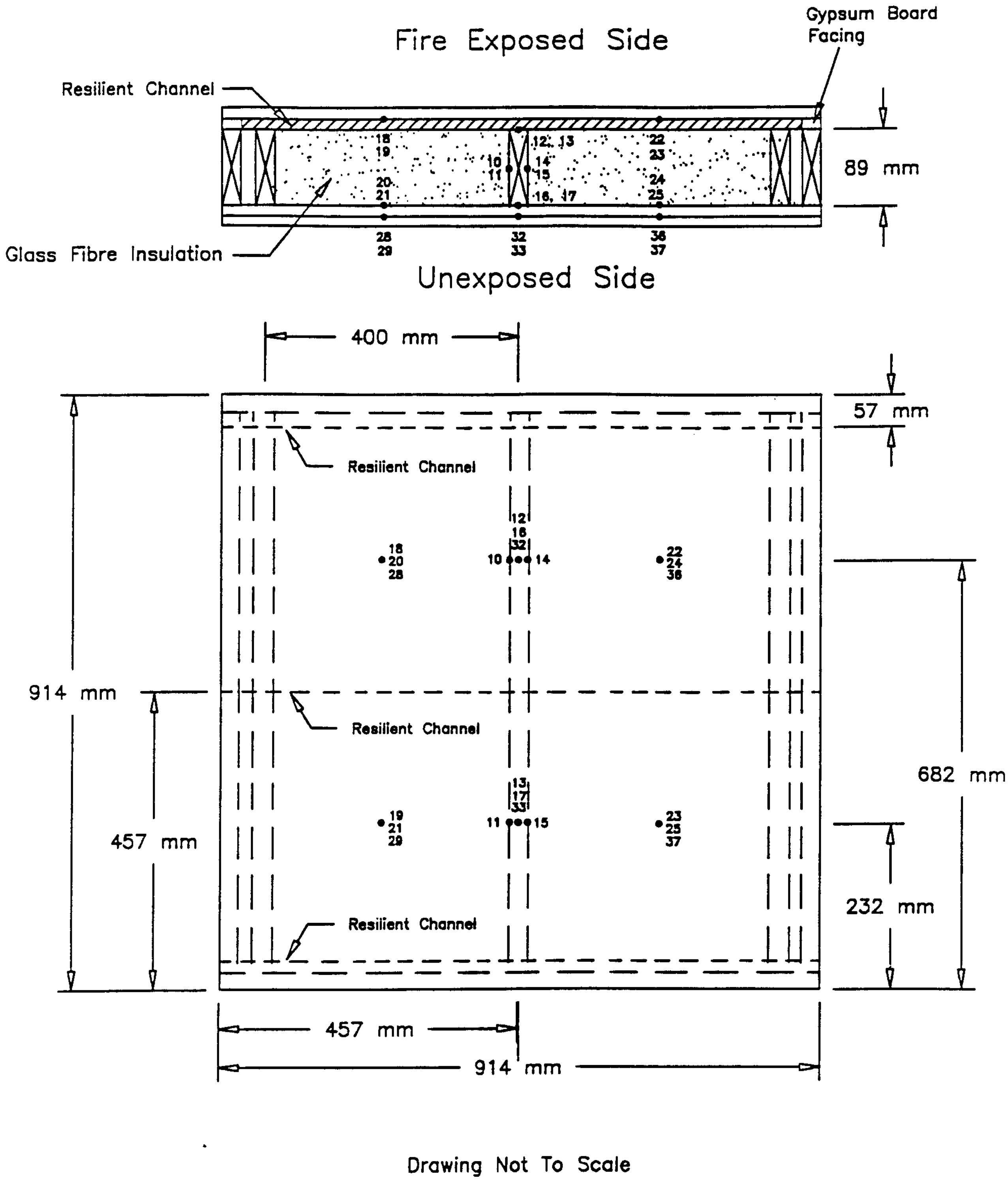


Figure 26. Thermocouple Locations in Small-Scale Test S-28

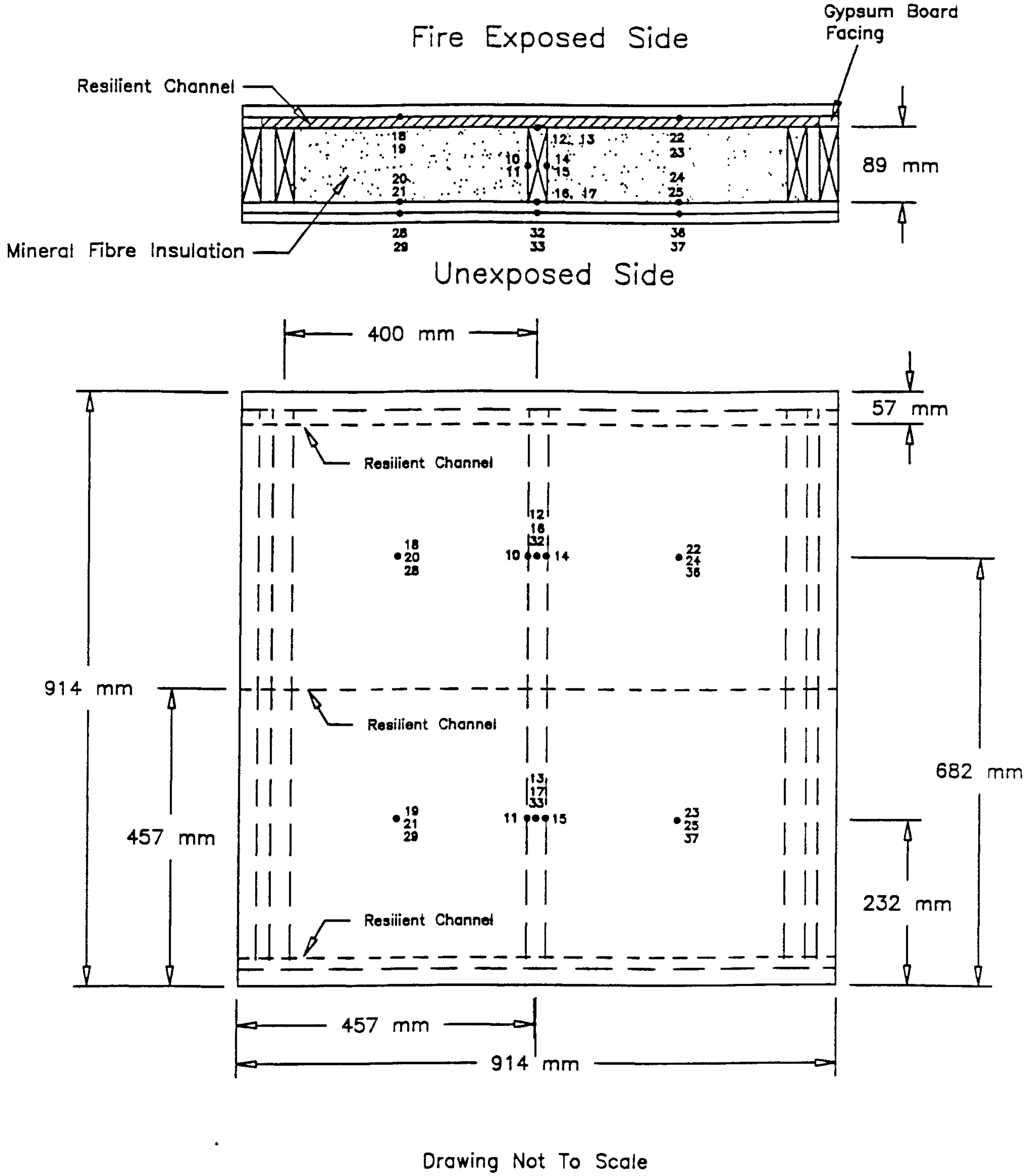


Figure 27. Thermocouple Locations in Small-Scale Test S-29

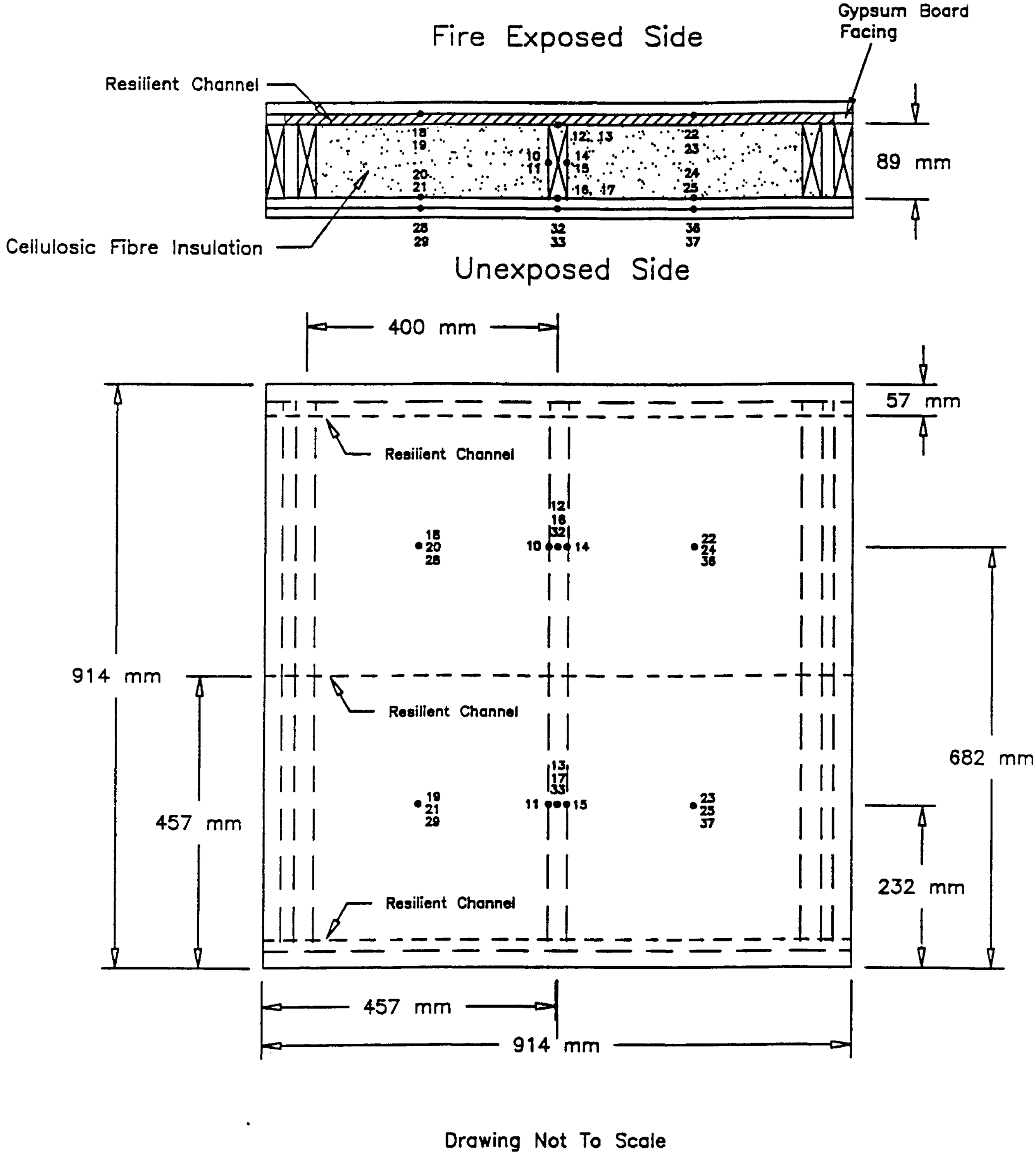


Figure 28. Thermocouple Locations in Small-Scale Test S-30

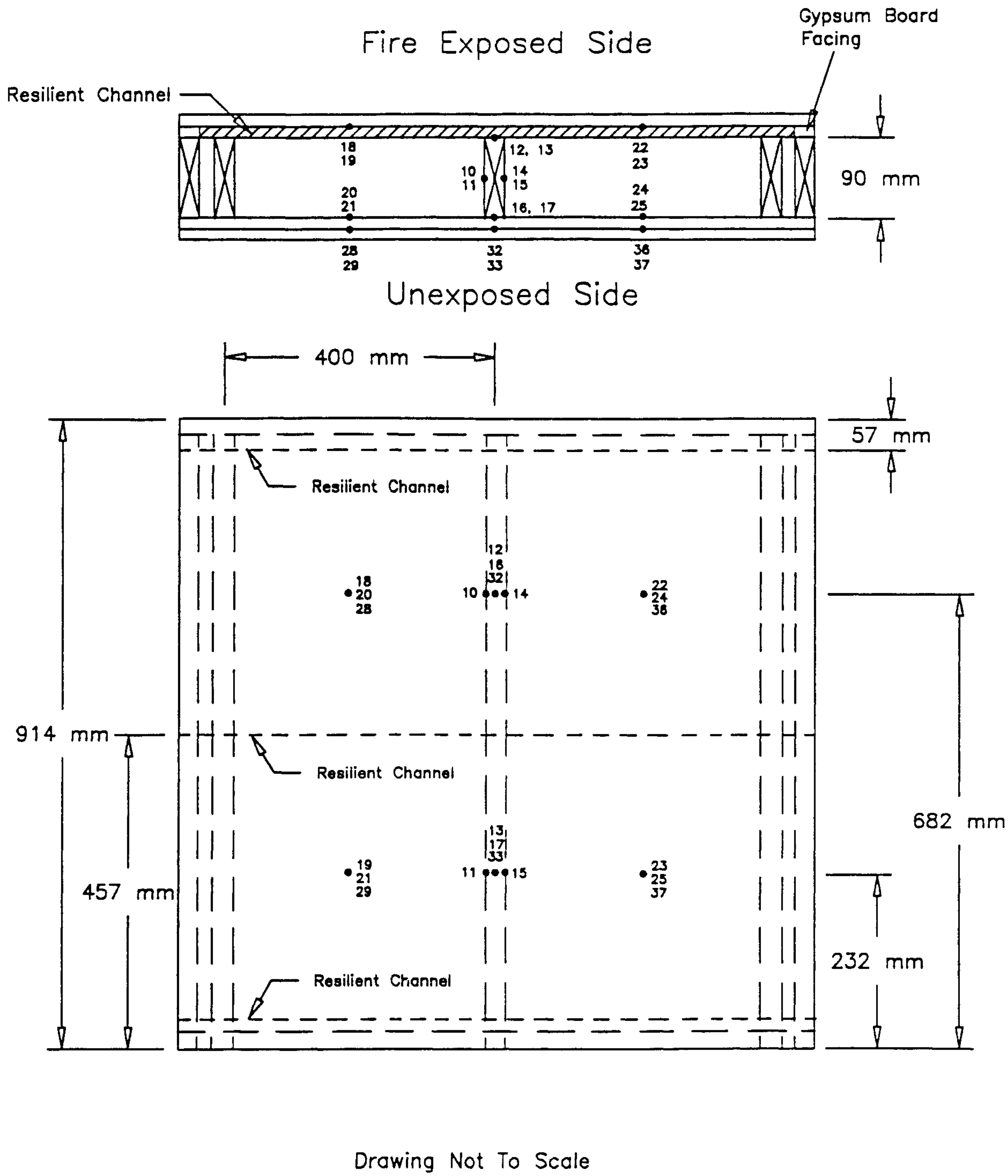


Figure 29. Thermocouple Locations in Small-Scale Test S-31

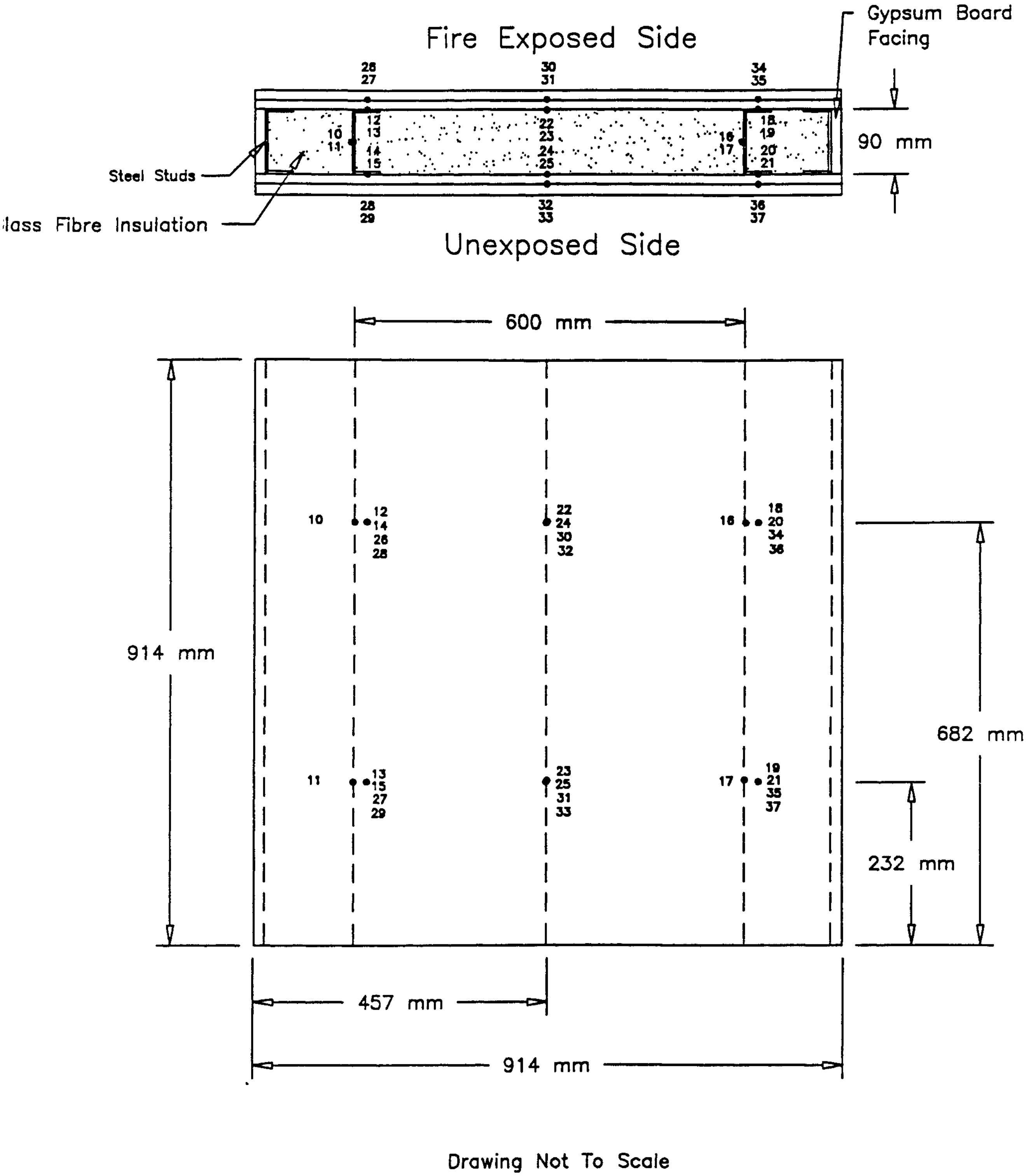


Figure 30. Thermocouple Locations in Small-Scale Test S-32

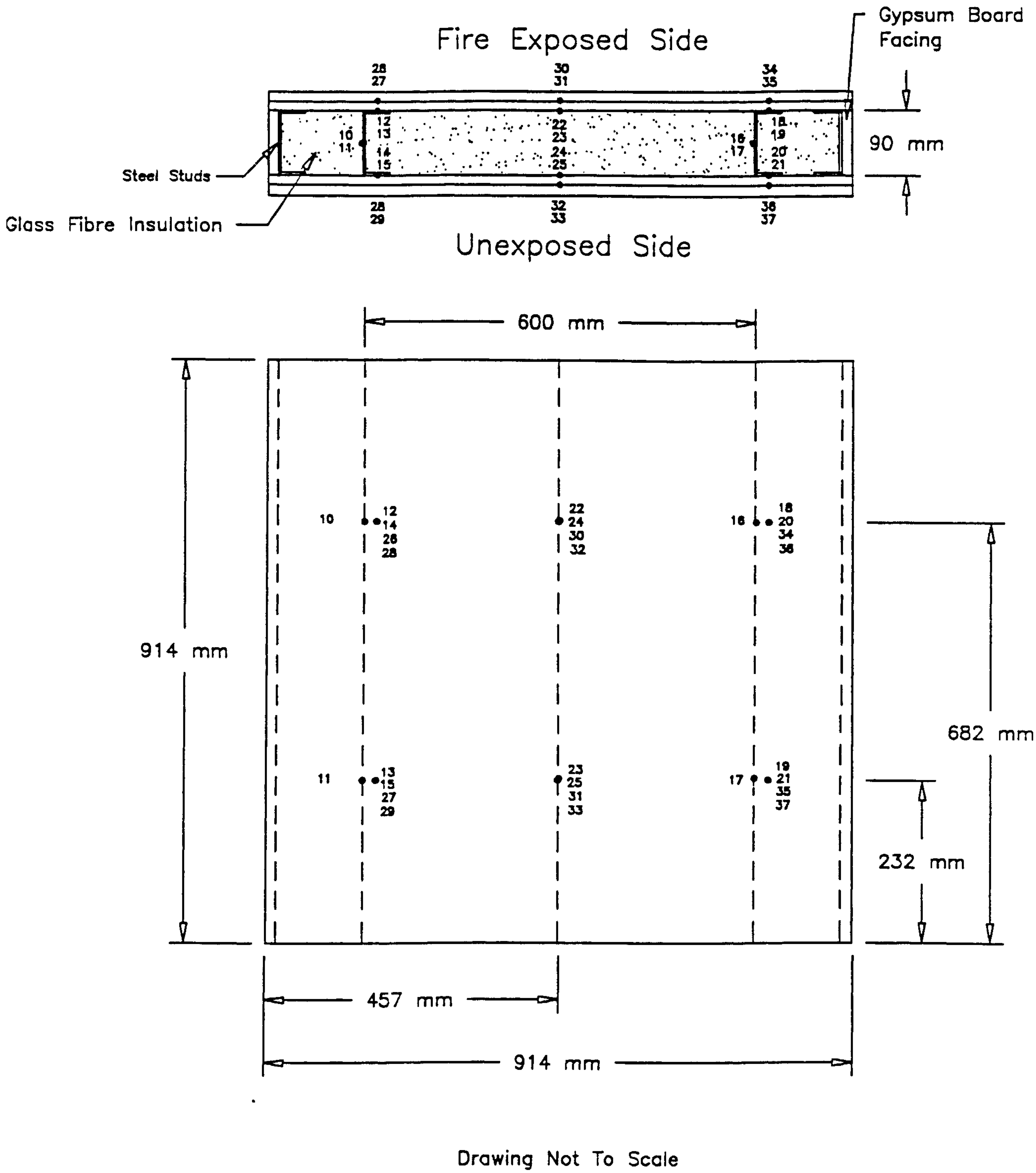


Figure 31. Thermocouple Locations in Small-Scale Test S-32B

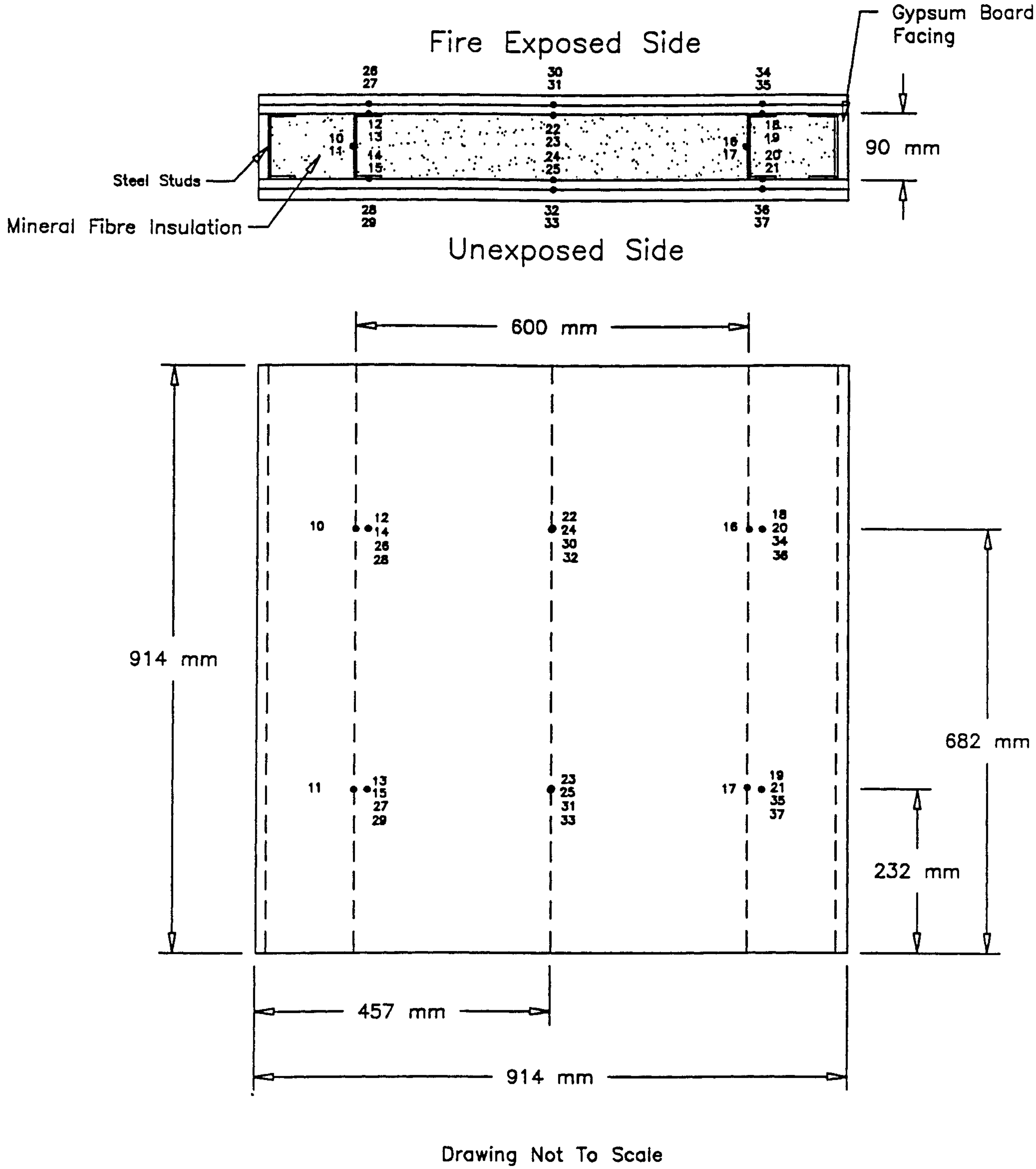


Figure 32. Thermocouple Locations in Small-Scale Test S-33

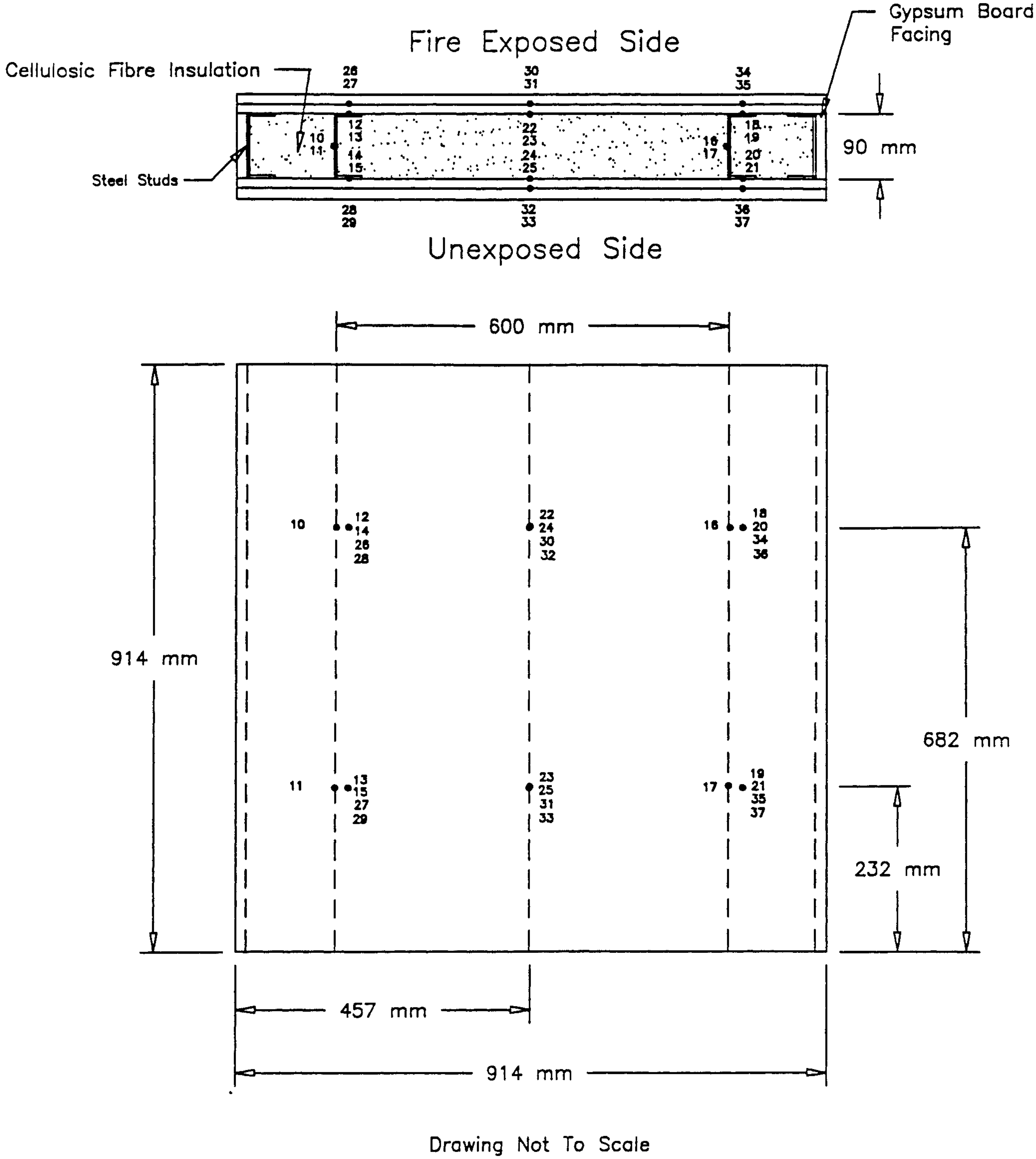


Figure 33. Thermocouple Locations in Small-Scale Test S-34

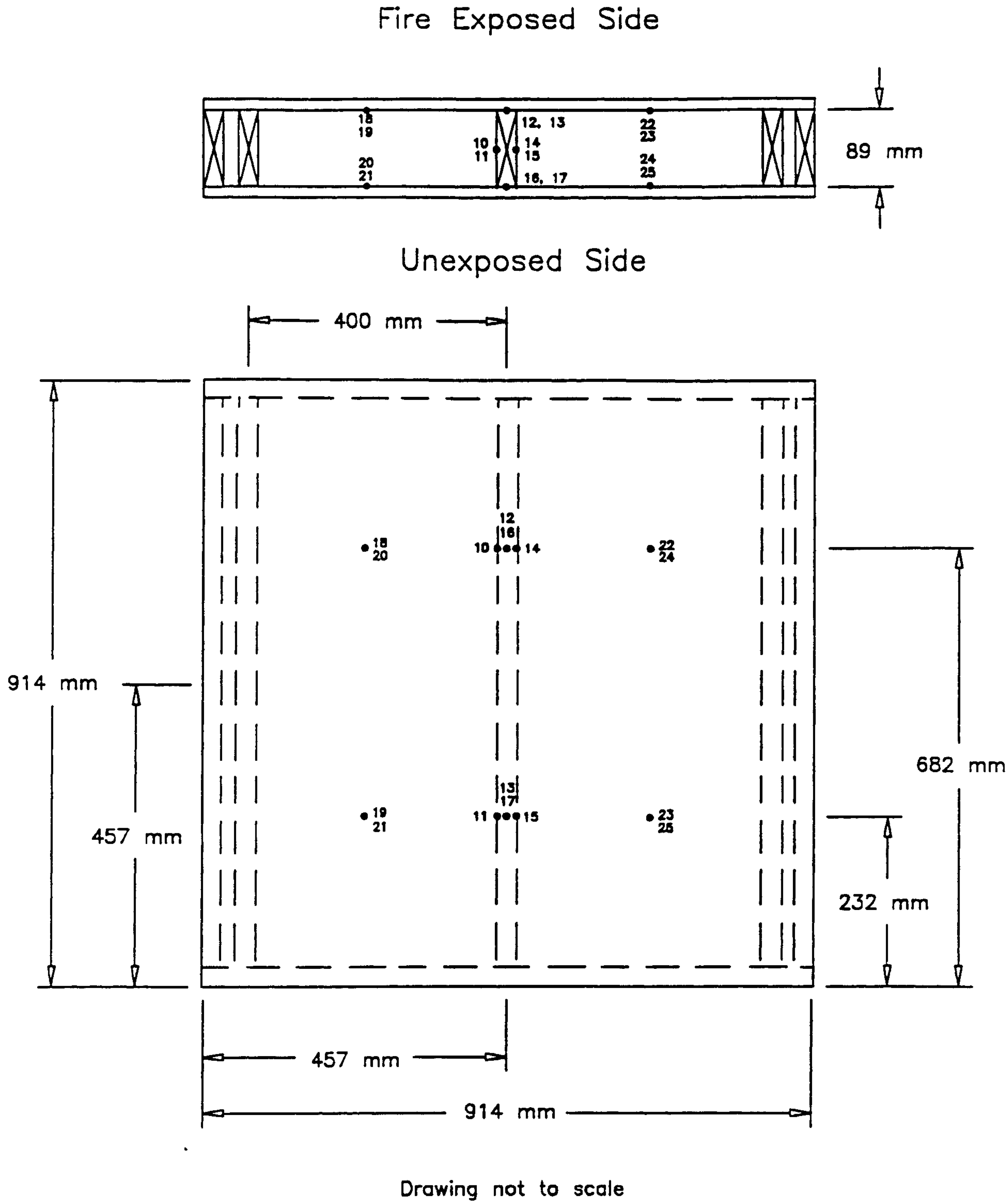


Figure 34. Thermocouple Locations in Small-Scale Test S-35

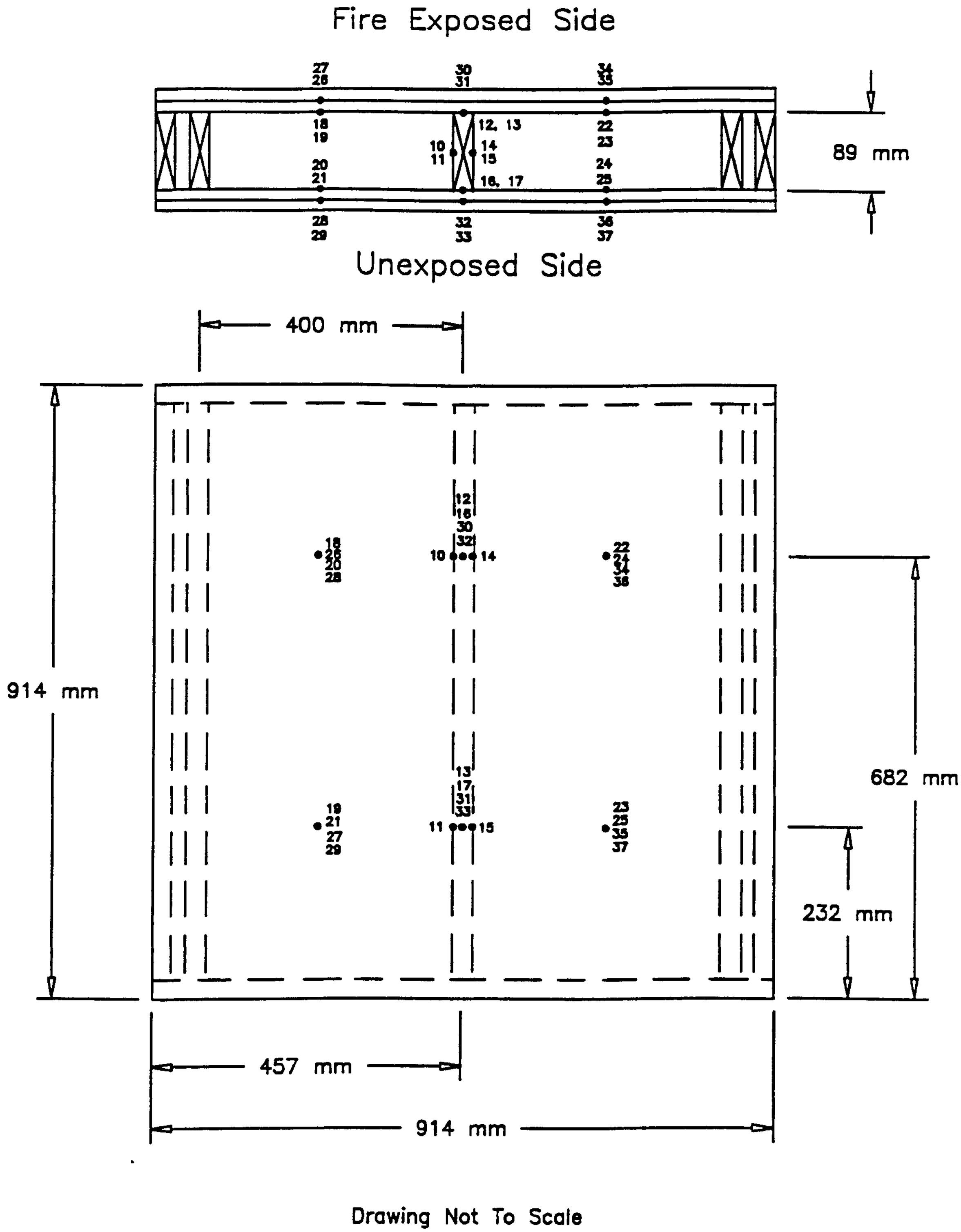
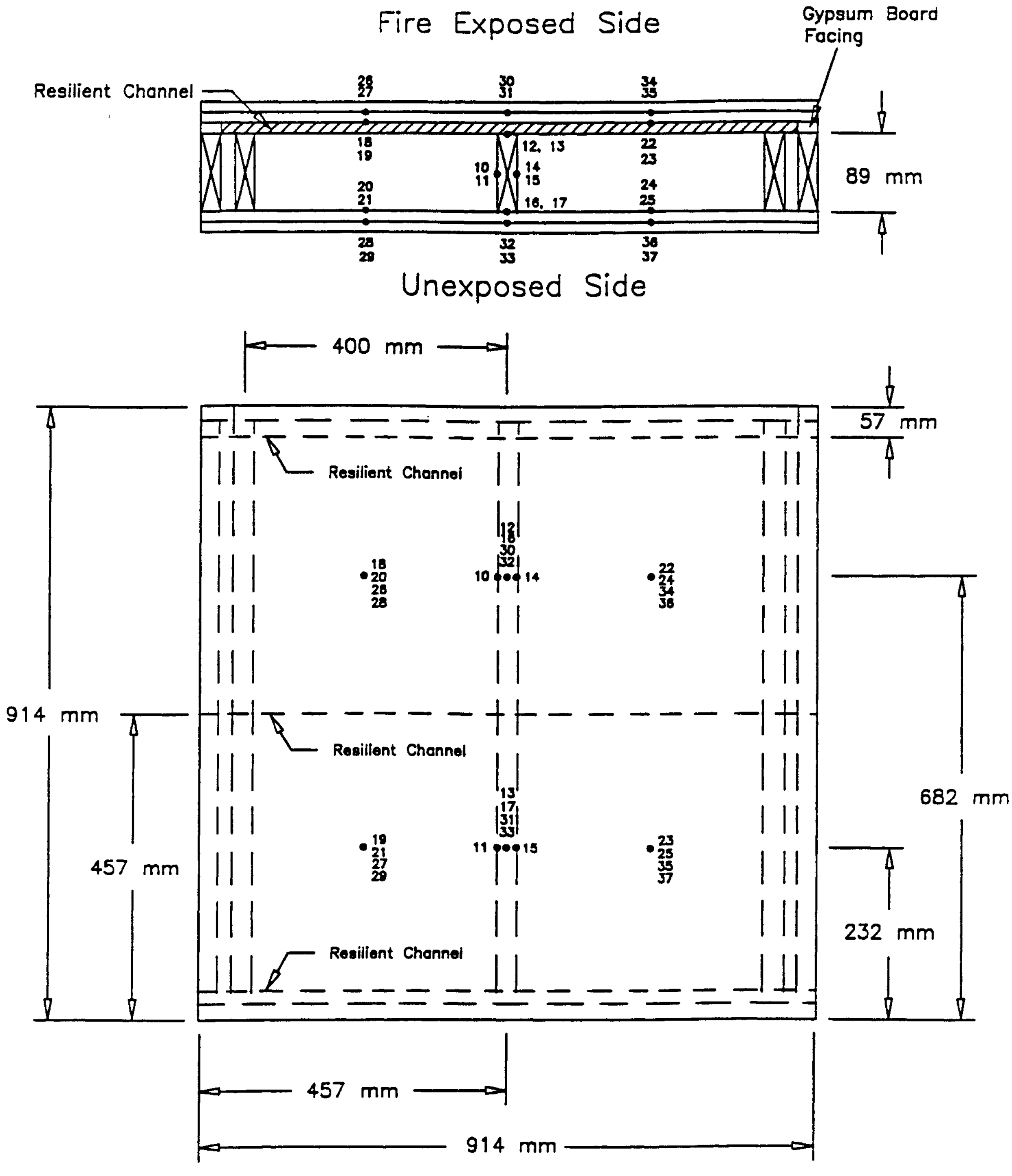


Figure 35. Thermocouple Locations in Small-Scale Test S-36



Drawing not to scale

Figure 36. Thermocouple Locations in Small-Scale Test S-37

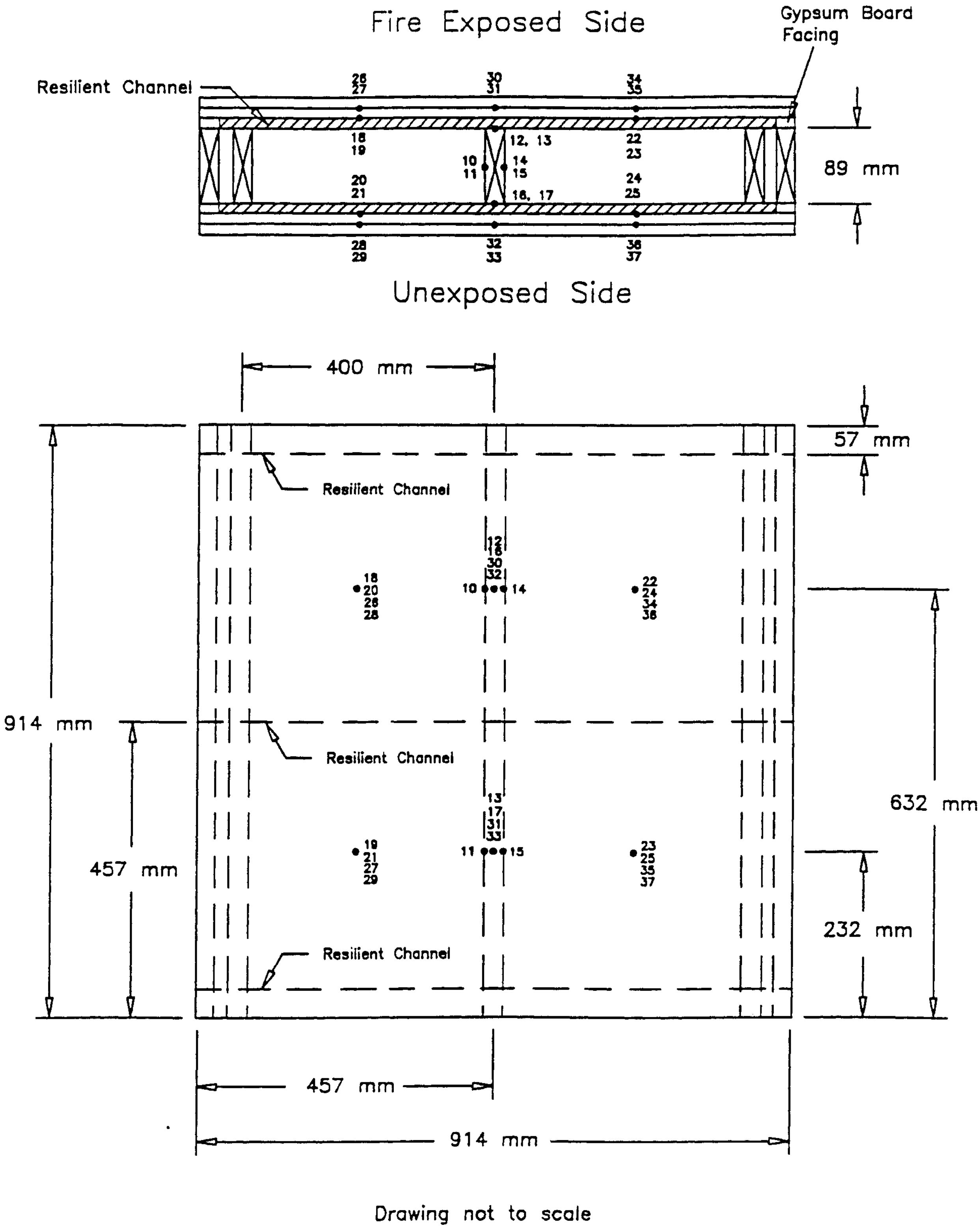


Figure 37. Thermocouple Locations in Small-Scale Test S-38

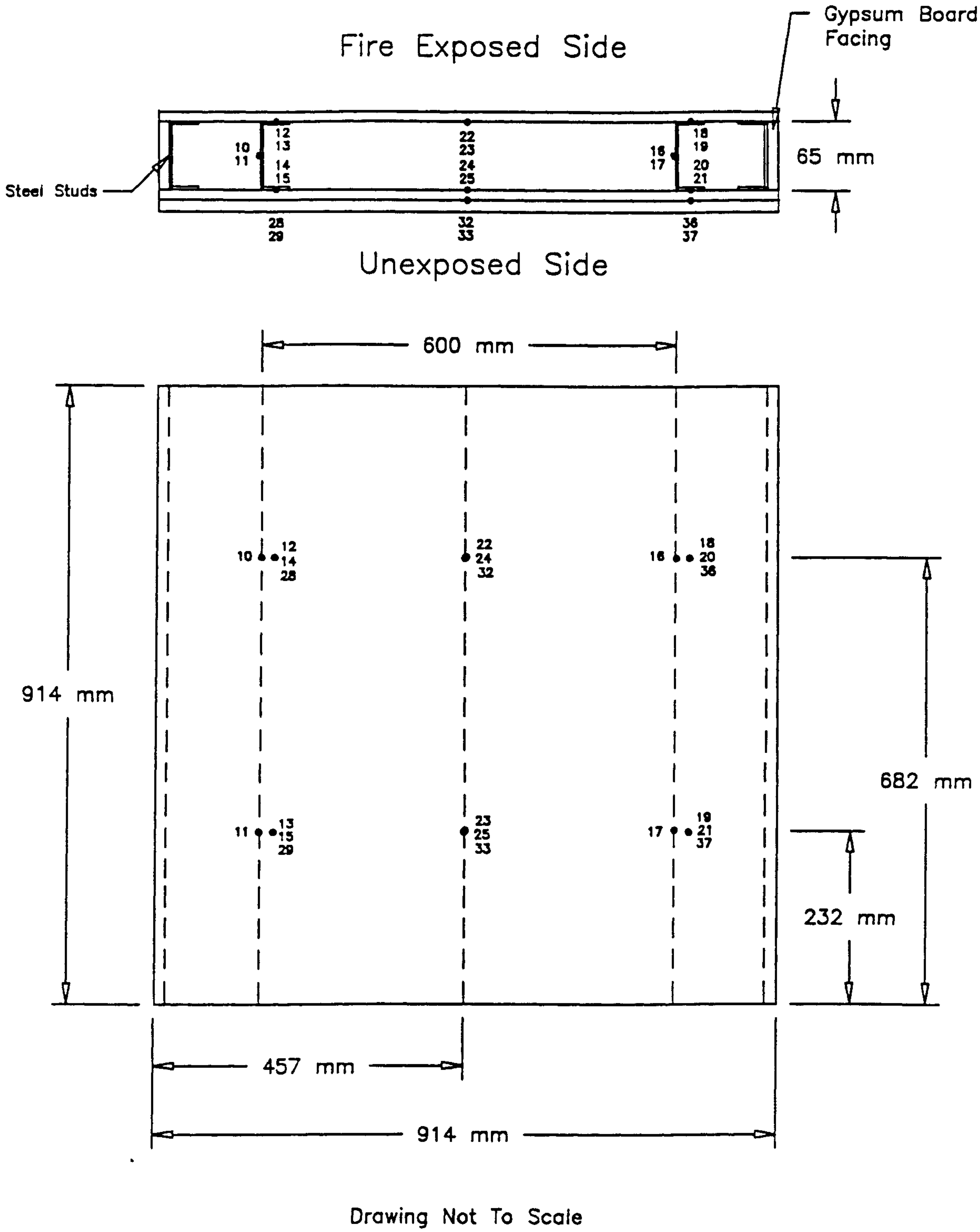


Figure 38. Thermocouple Locations in Small-Scale Test S-39

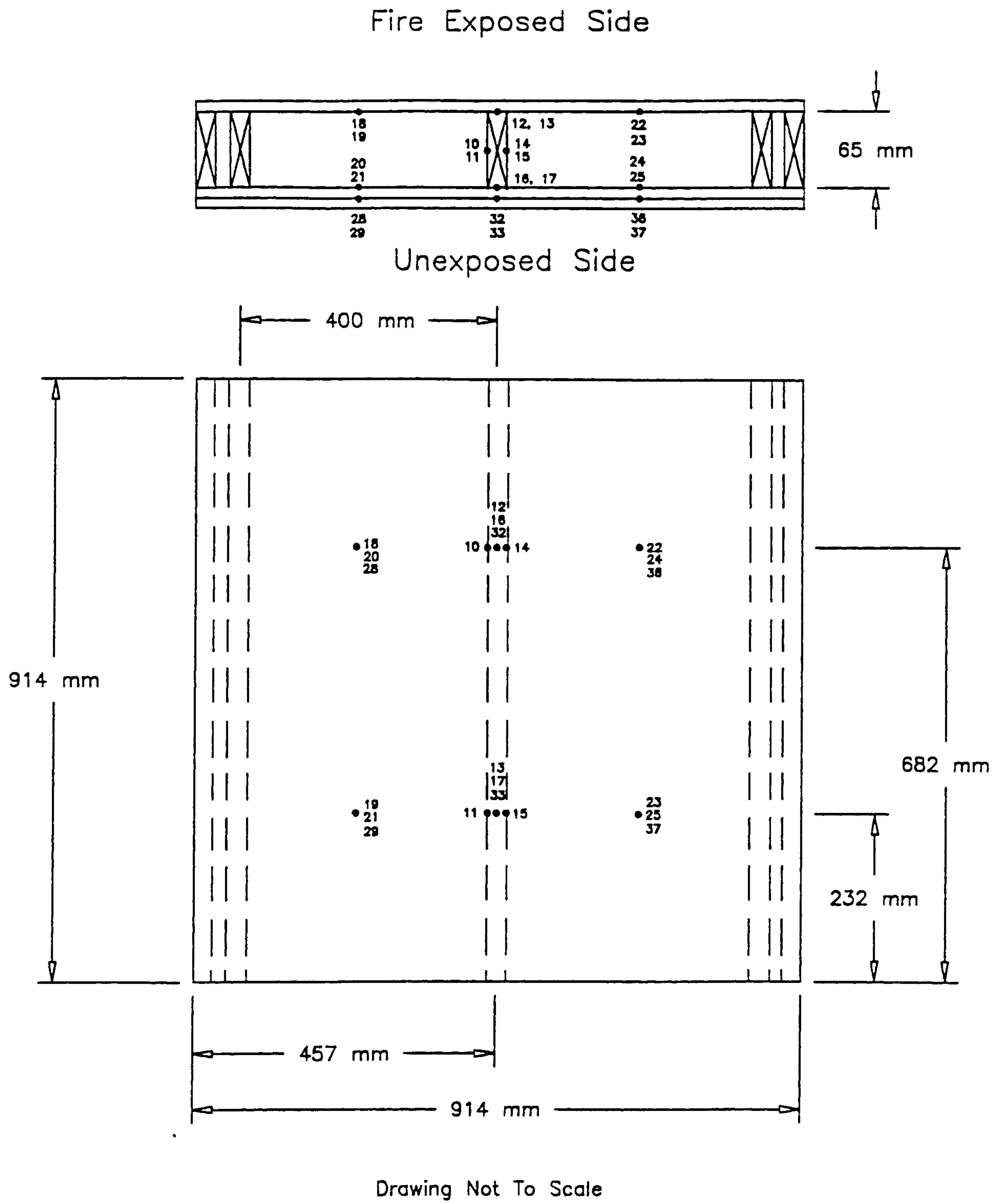


Figure 39. Thermocouple Locations in Small-Scale Test S-40

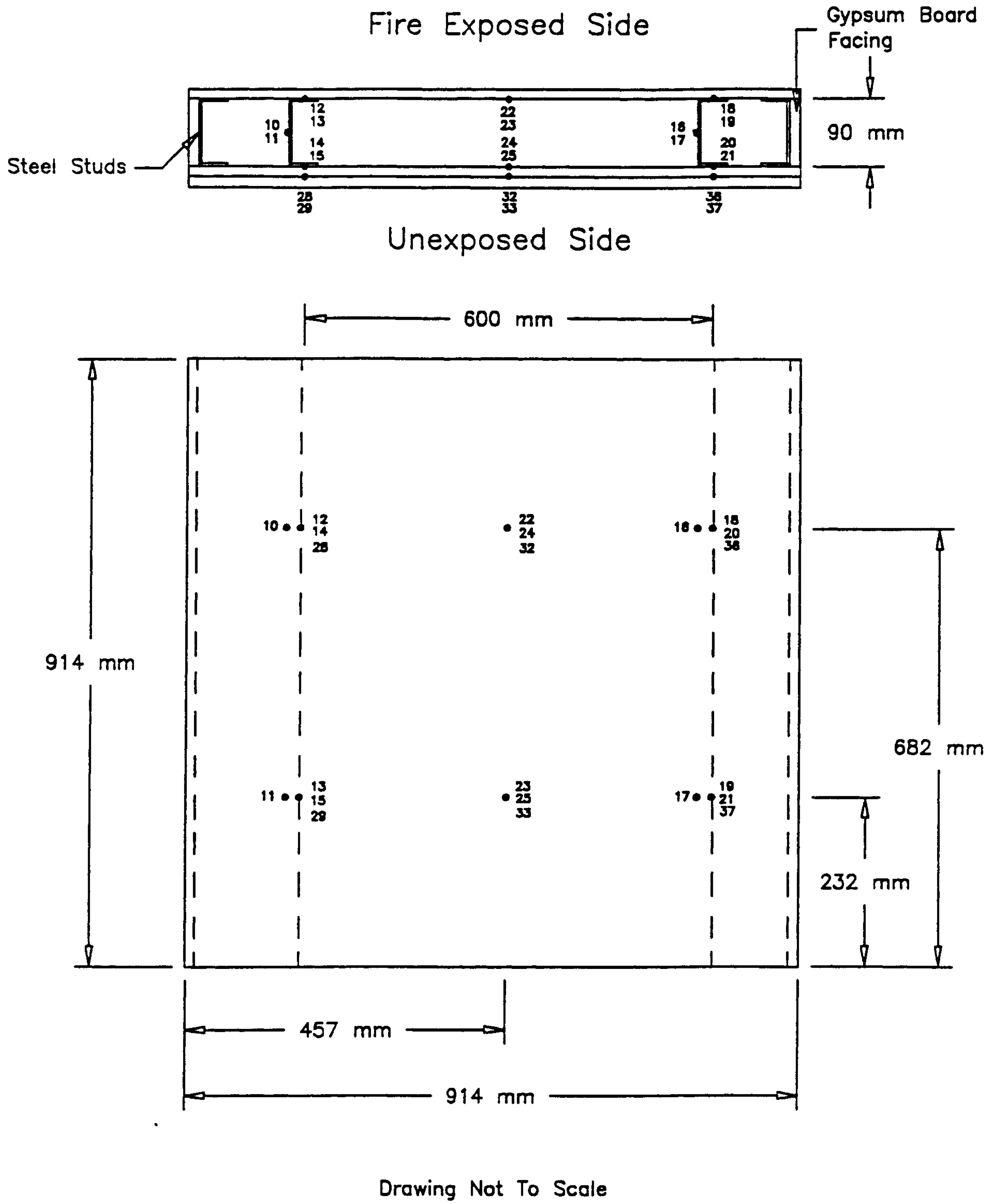


Figure 40. Thermocouple Locations in Small-Scale Test S-41

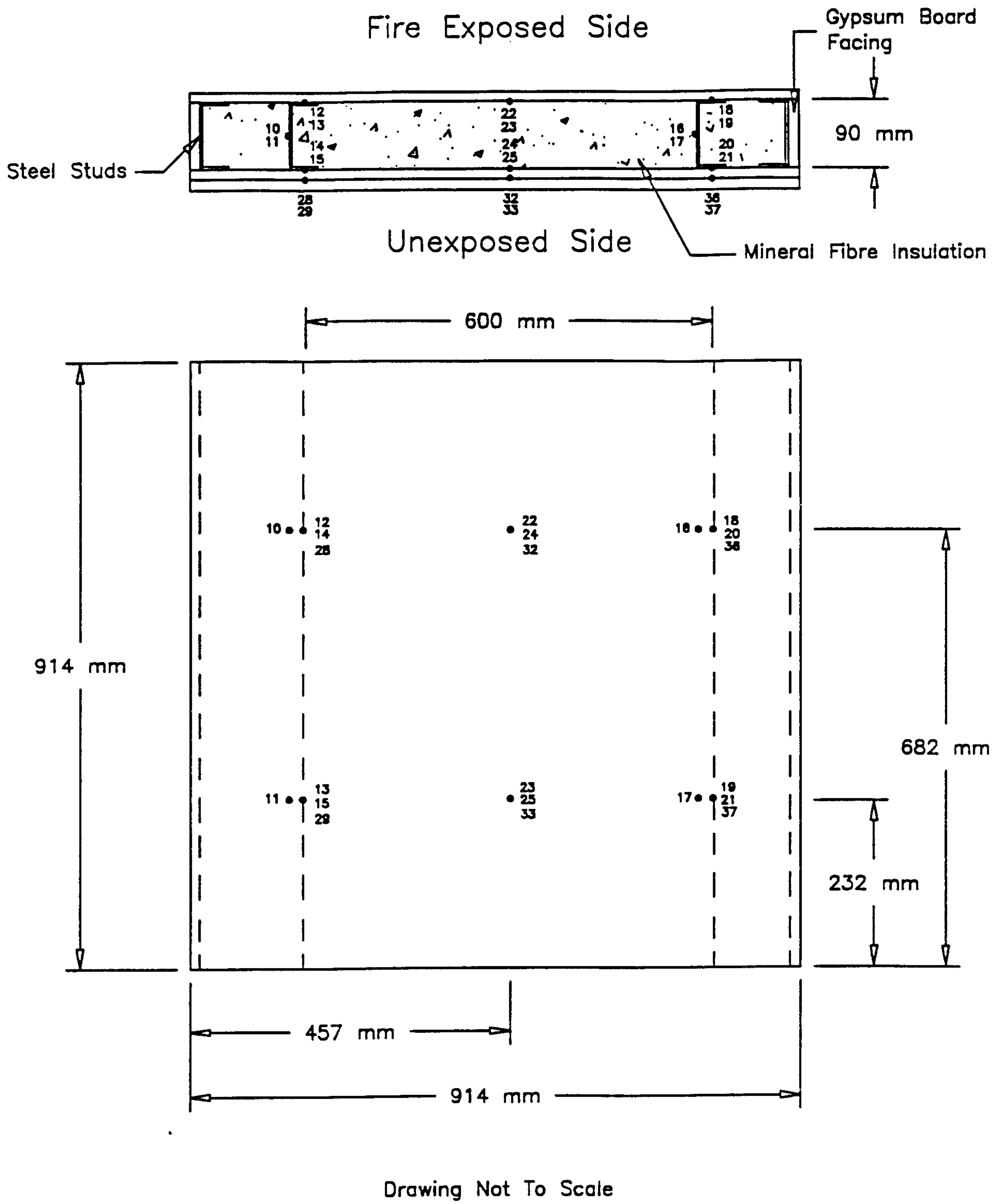


Figure 41. Thermocouple Locations in Small-Scale Test S-42

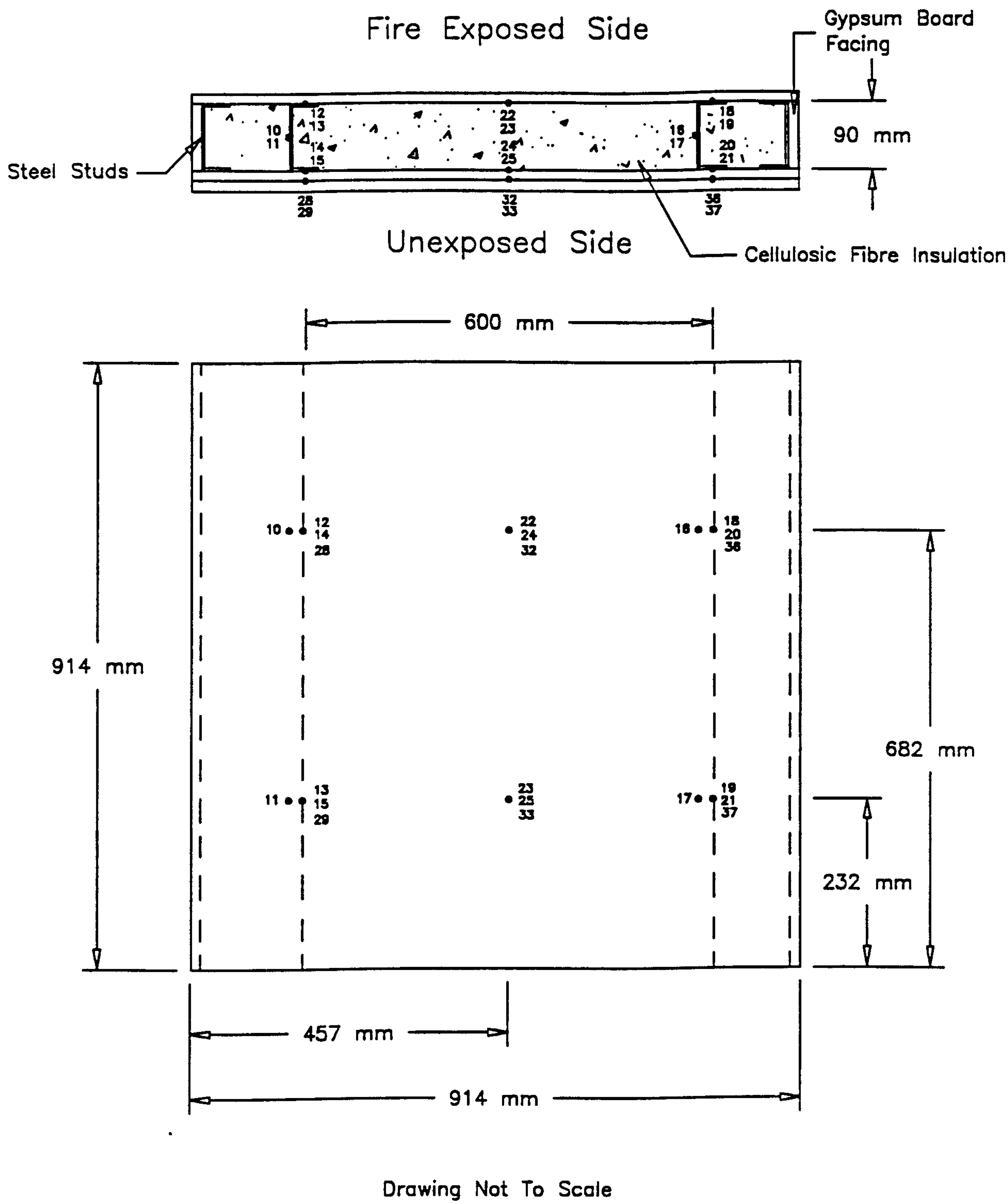


Figure 42. Thermocouple Locations in Small-Scale Test S-43

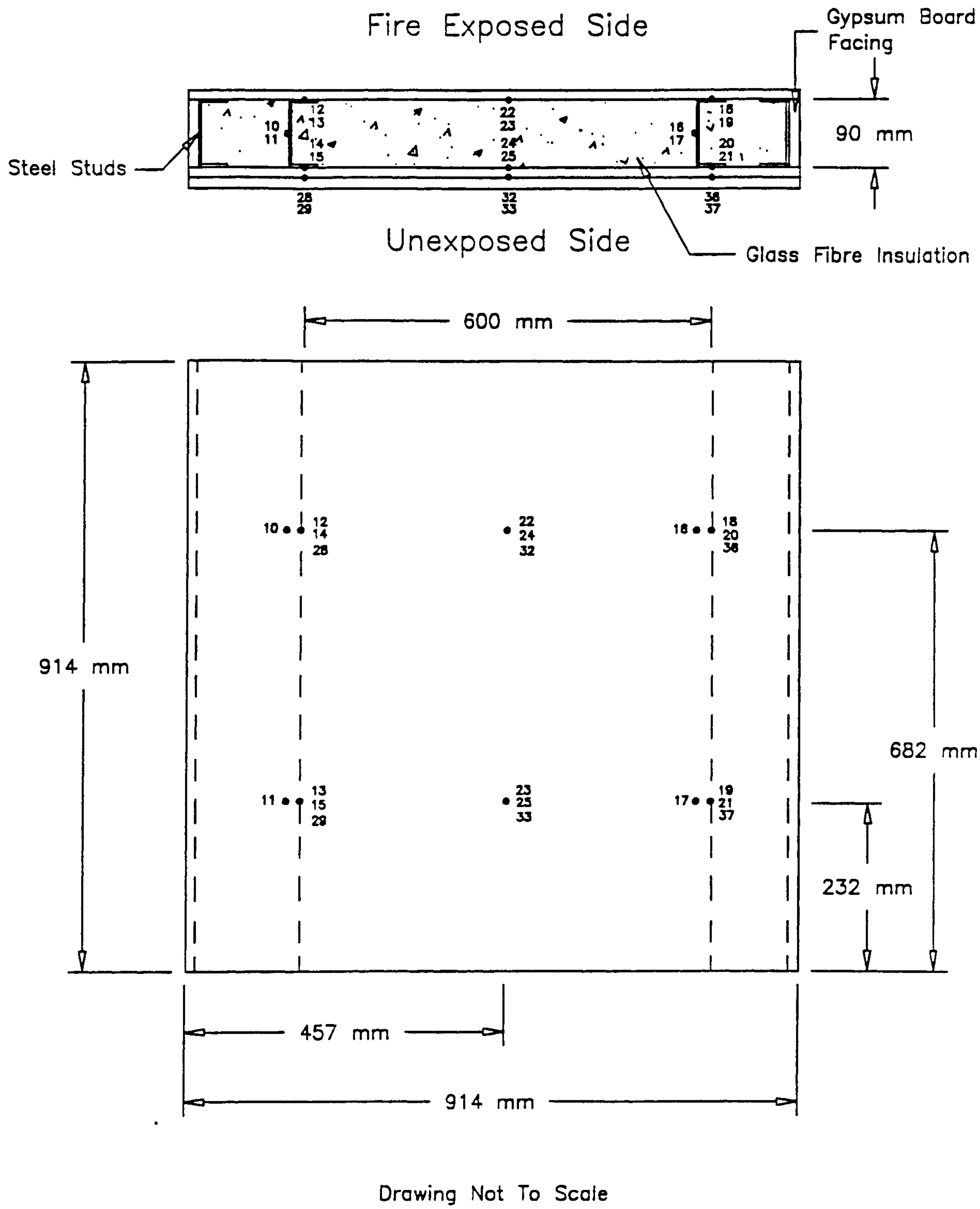


Figure 43. Thermocouple Locations in Small-Scale Test S-44

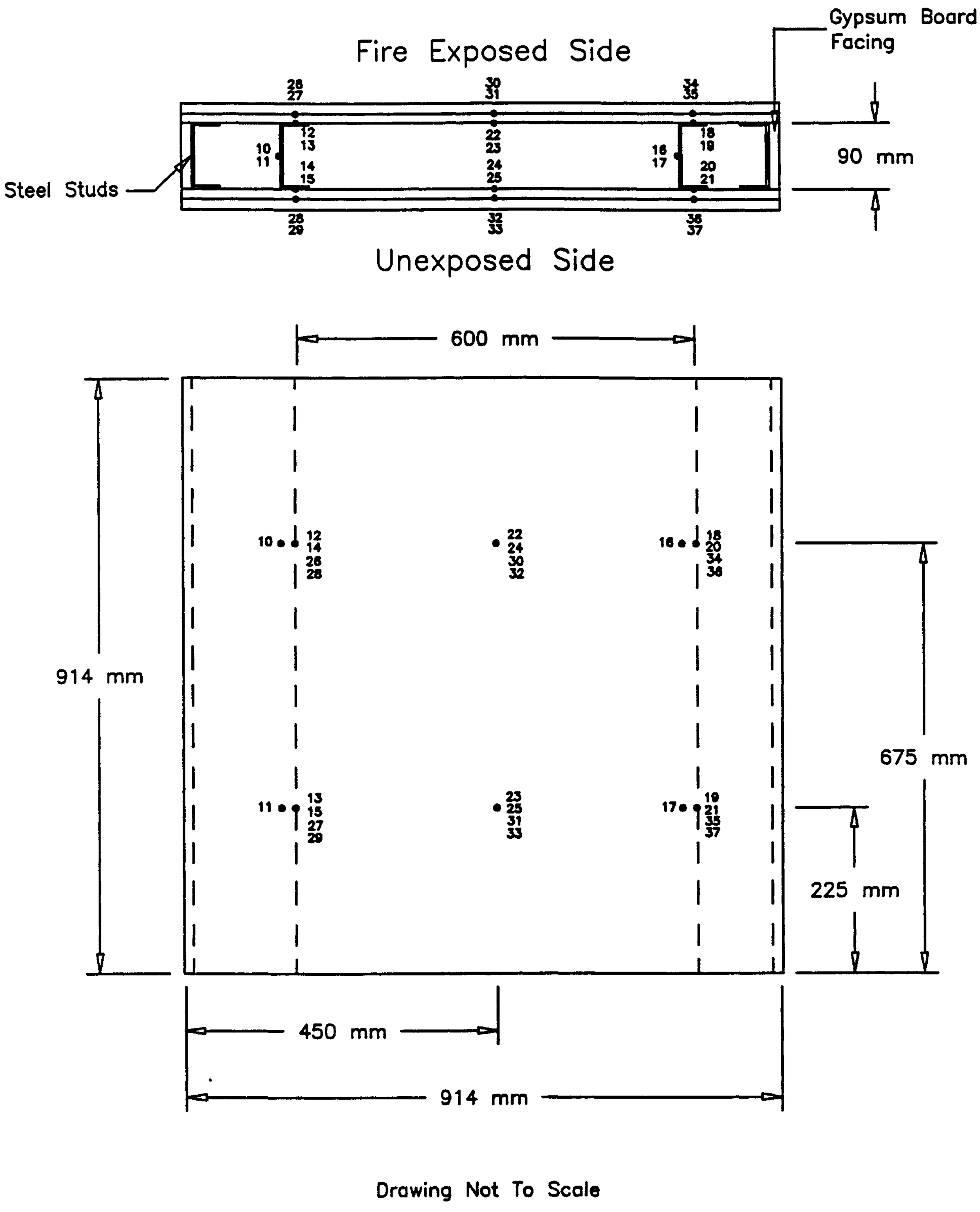


Figure 44. Thermocouple Locations in Small-Scale Test S-45

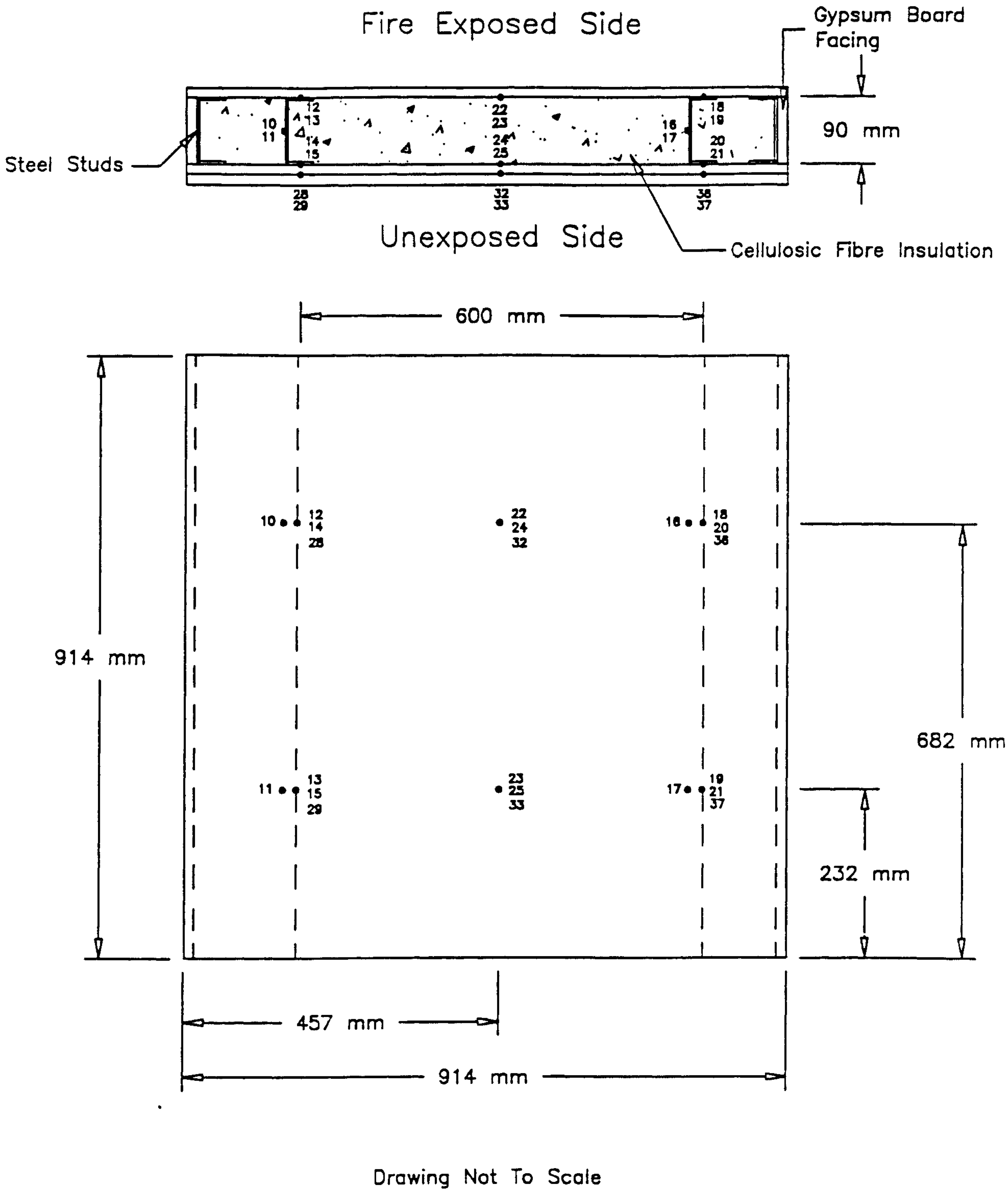
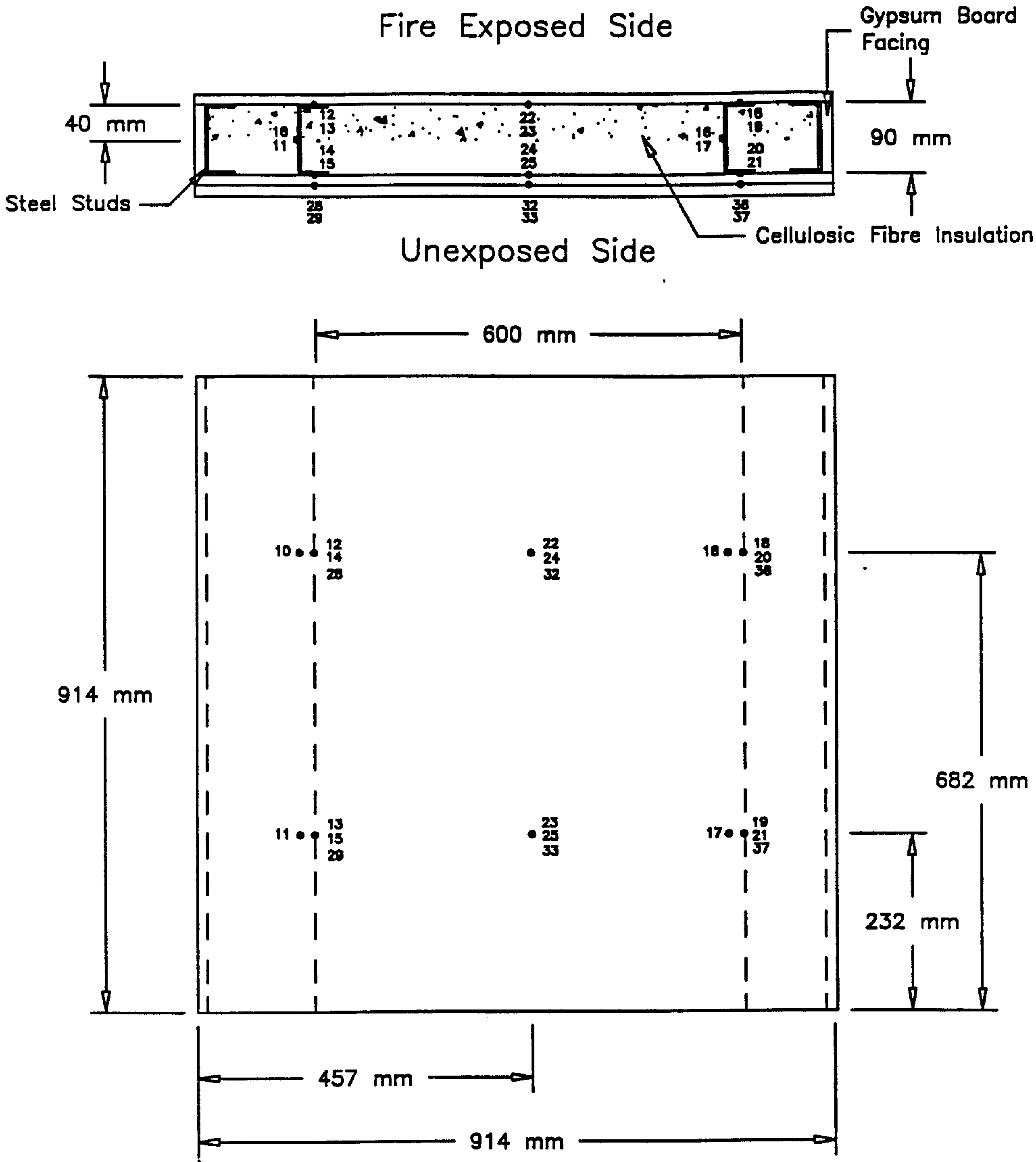


Figure 45. Thermocouple Locations in Small-Scale Test S-46



Drawing Not To Scale

Figure 46. Thermocouple Locations in Small-Scale Test S-47

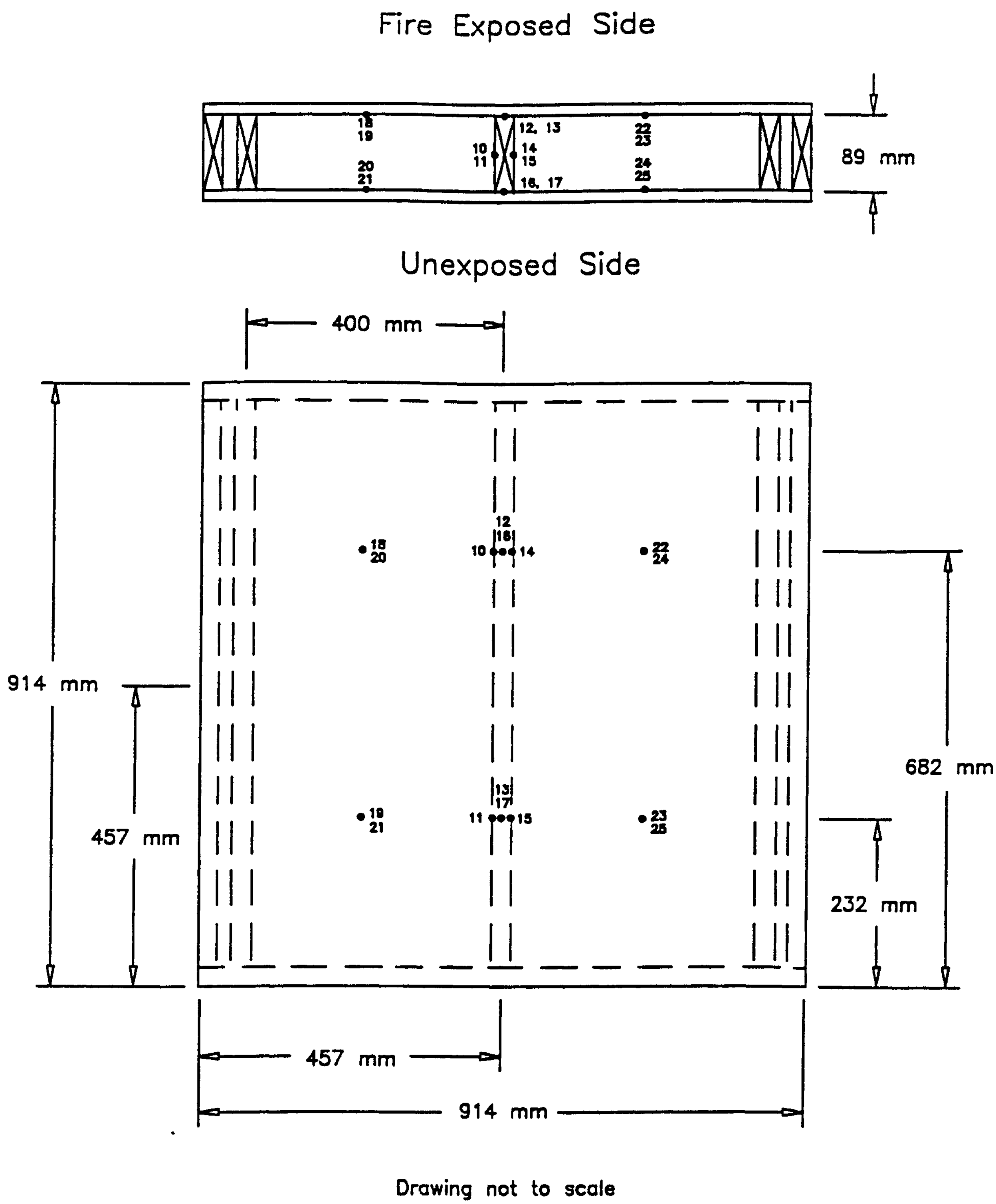


Figure 47. Thermocouple Locations in Small-Scale Test S-48

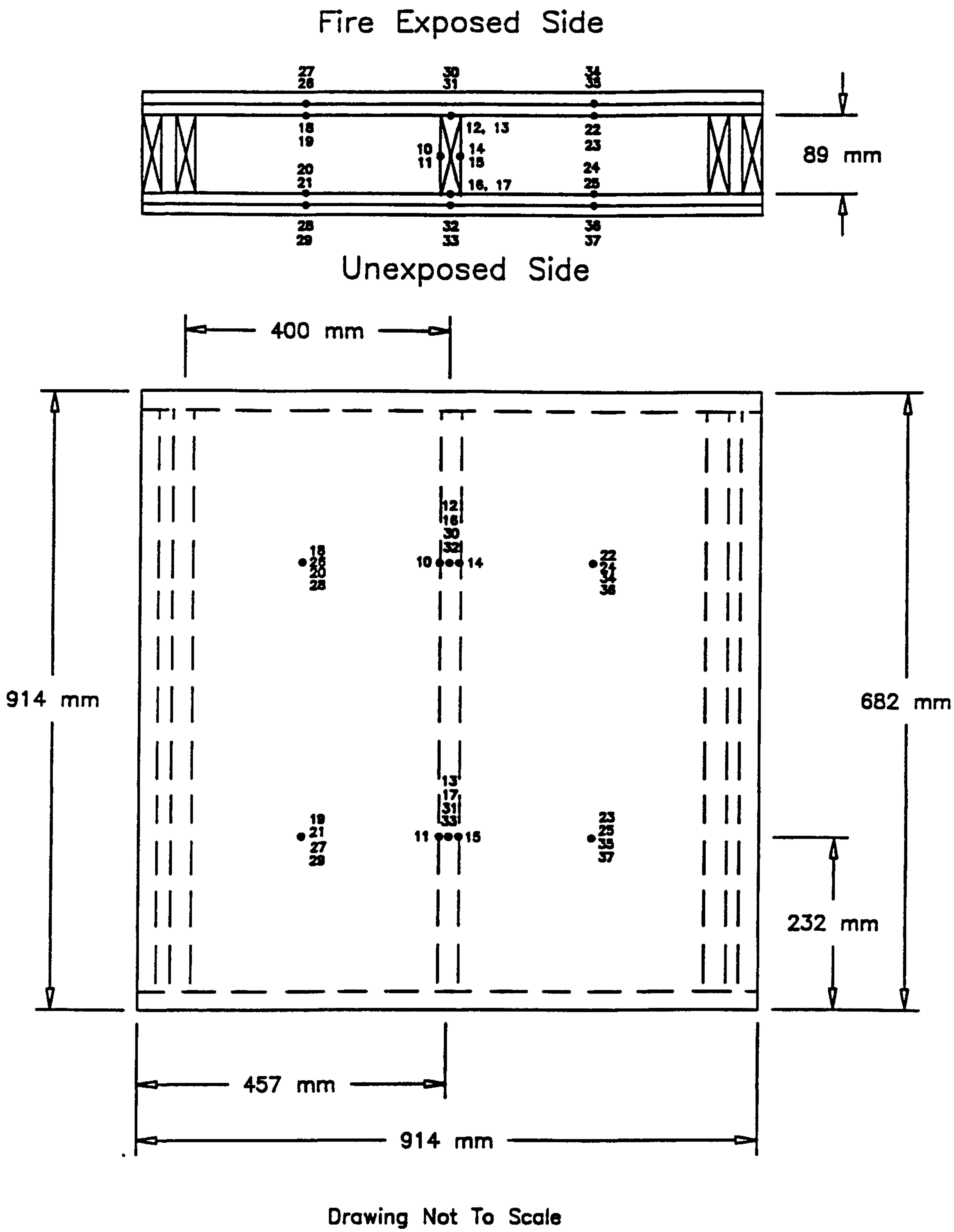
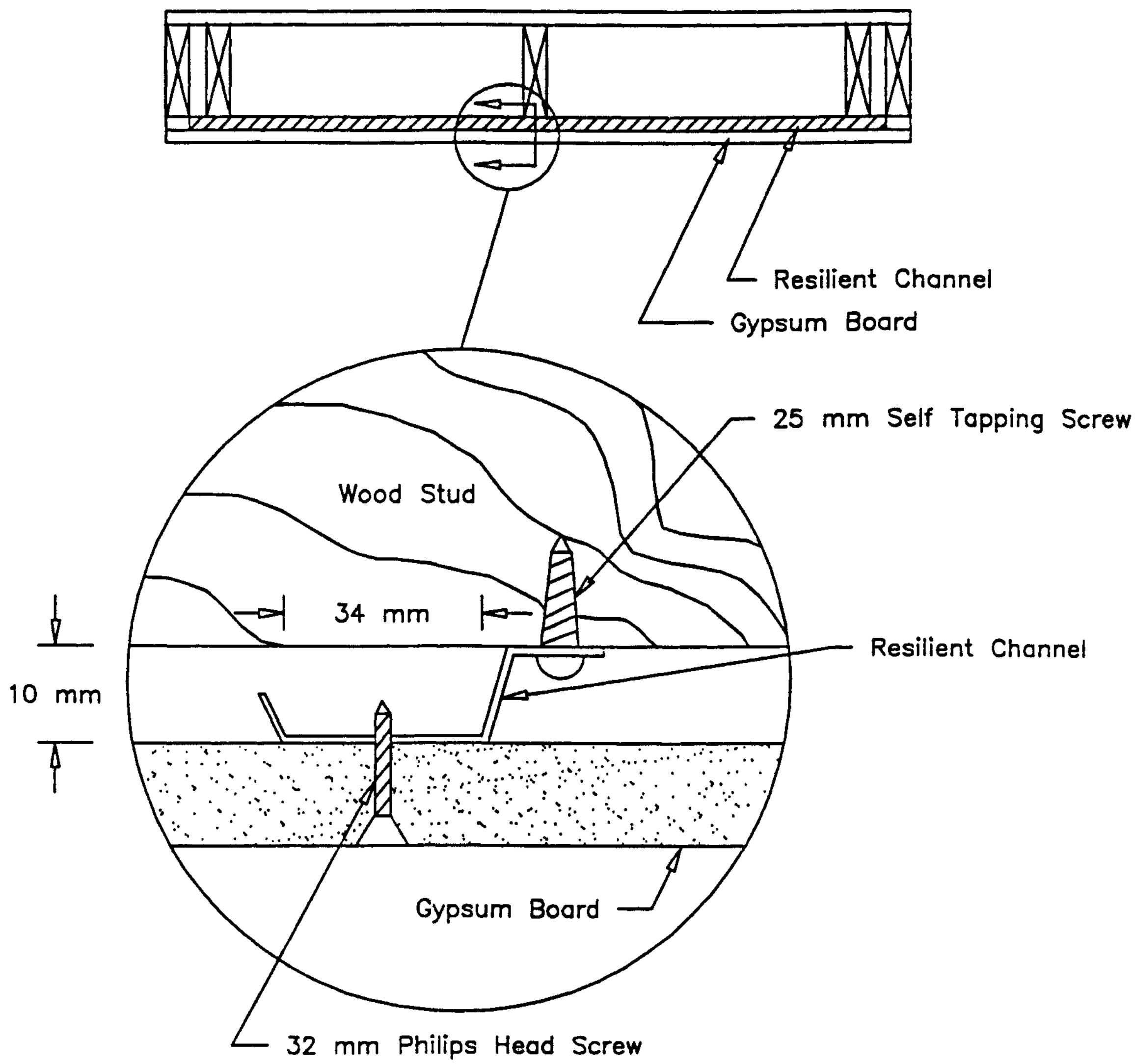


Figure 48. Thermocouple Locations in Small-Scale Test S-49



. Edge View: Resilient Channel

Drawing not to scale

Figure 49. Resilient Channel Installation Detail

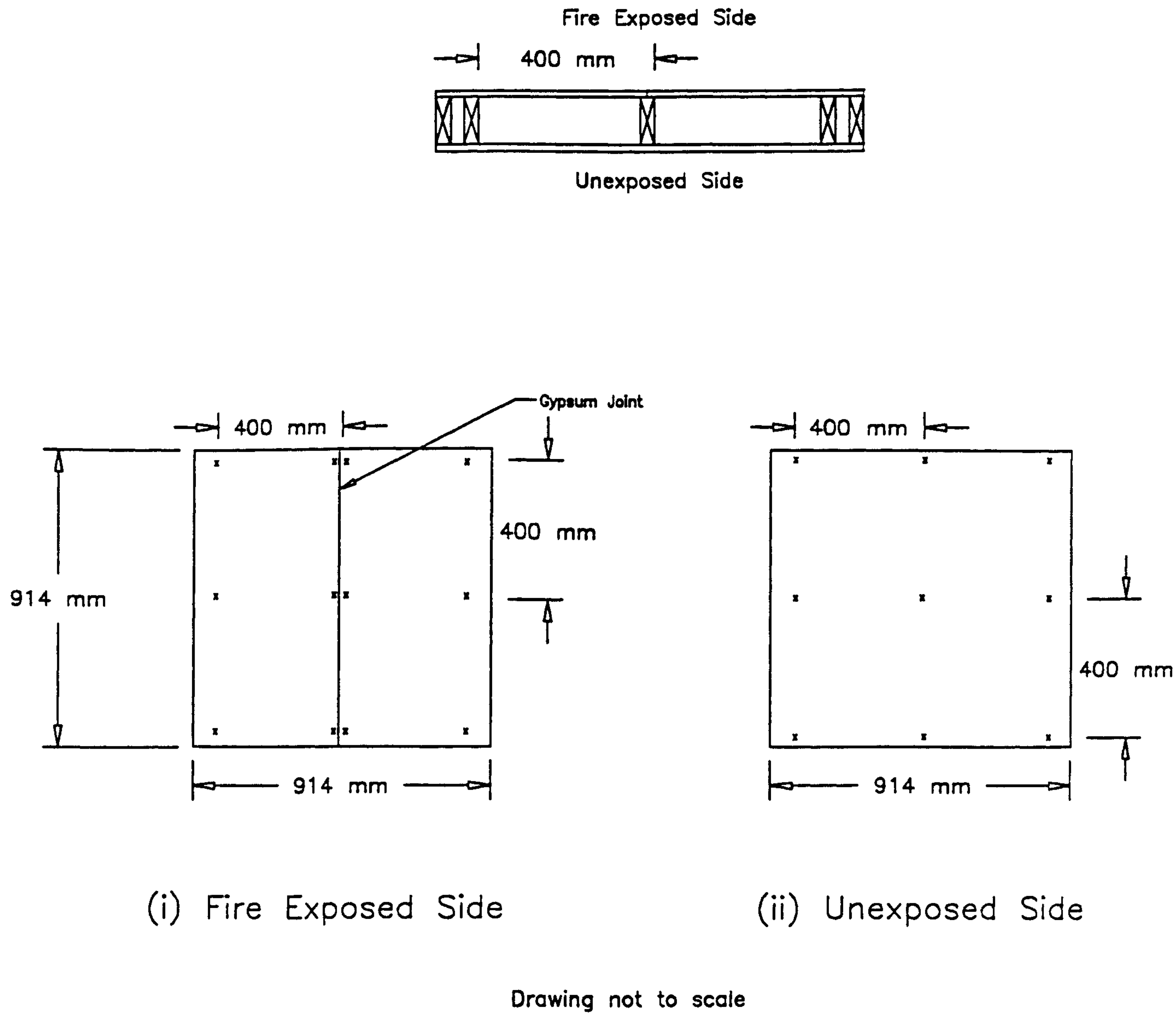


Figure 50. Screw Locations For Wood Stud, 1x1 Gypsum Layers, Small-Scale Assemblies

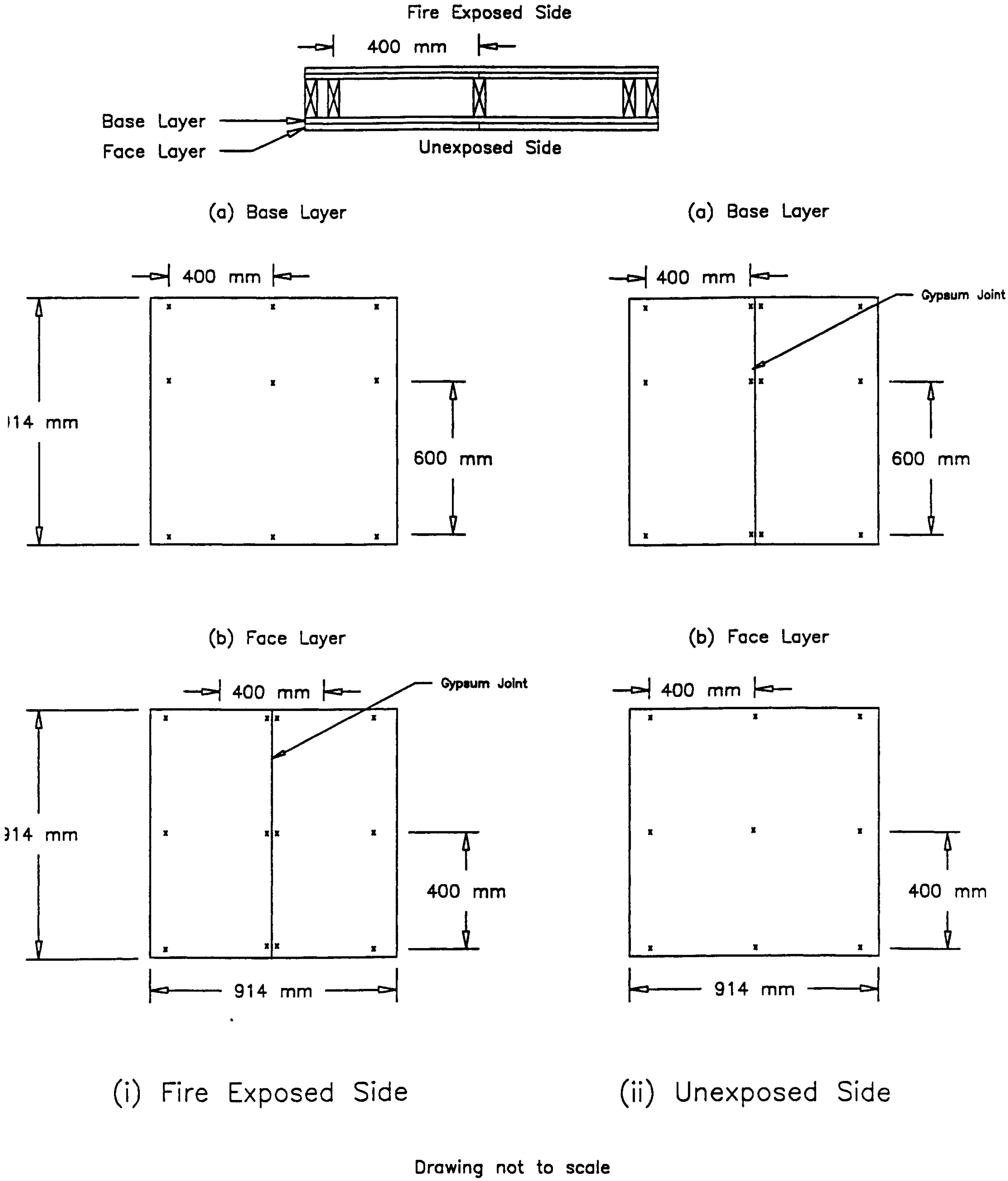


Figure 51. Screw Locations For Wood Stud, 2x2 Gypsum Layers, Small-Scale Assemblies (400 mm Stud Spacing)

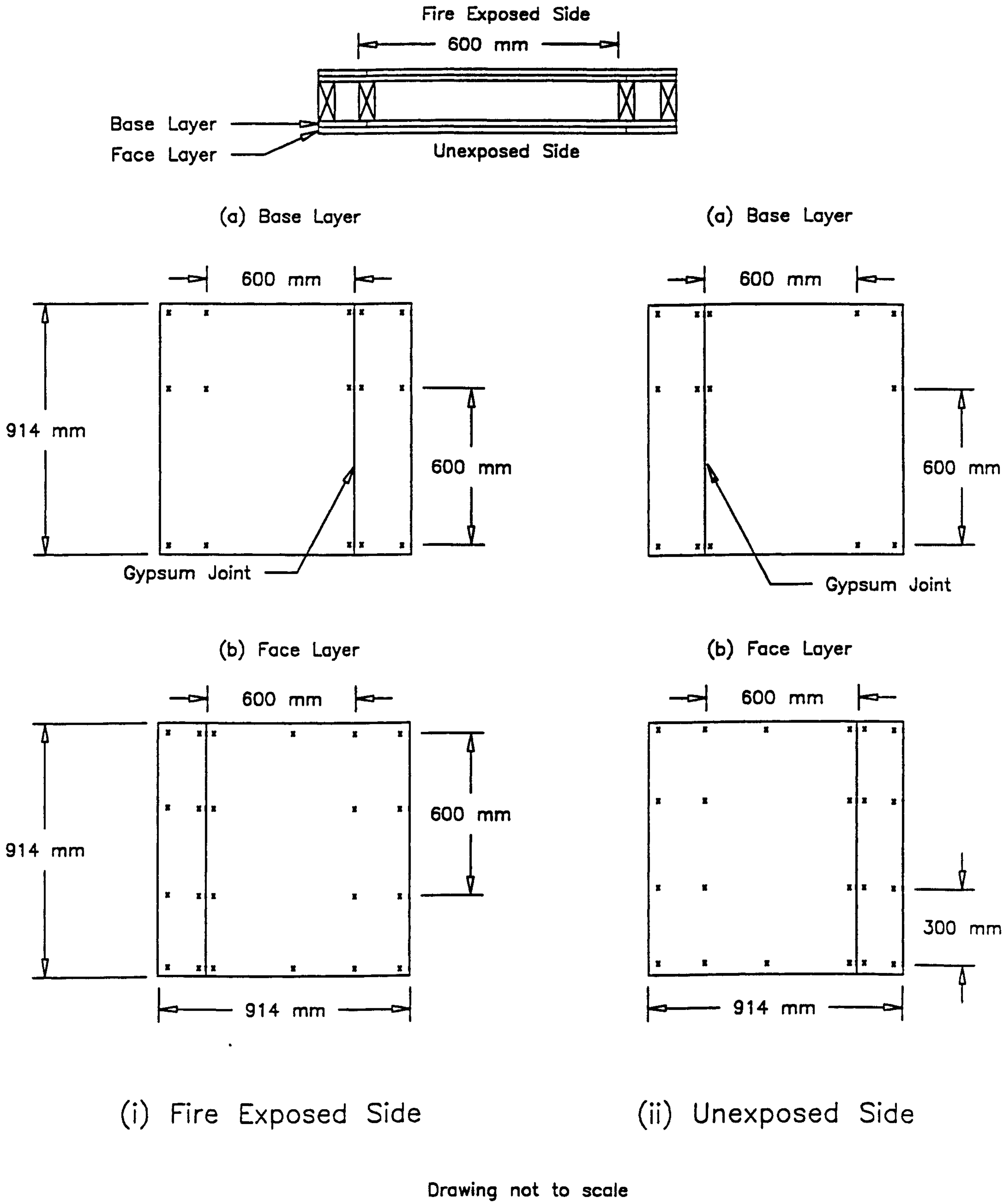


Figure 52. Screw Locations For Wood Stud, 2x2 Gypsum Layers, Small-Scale Assemblies (600 mm Stud Spacing)

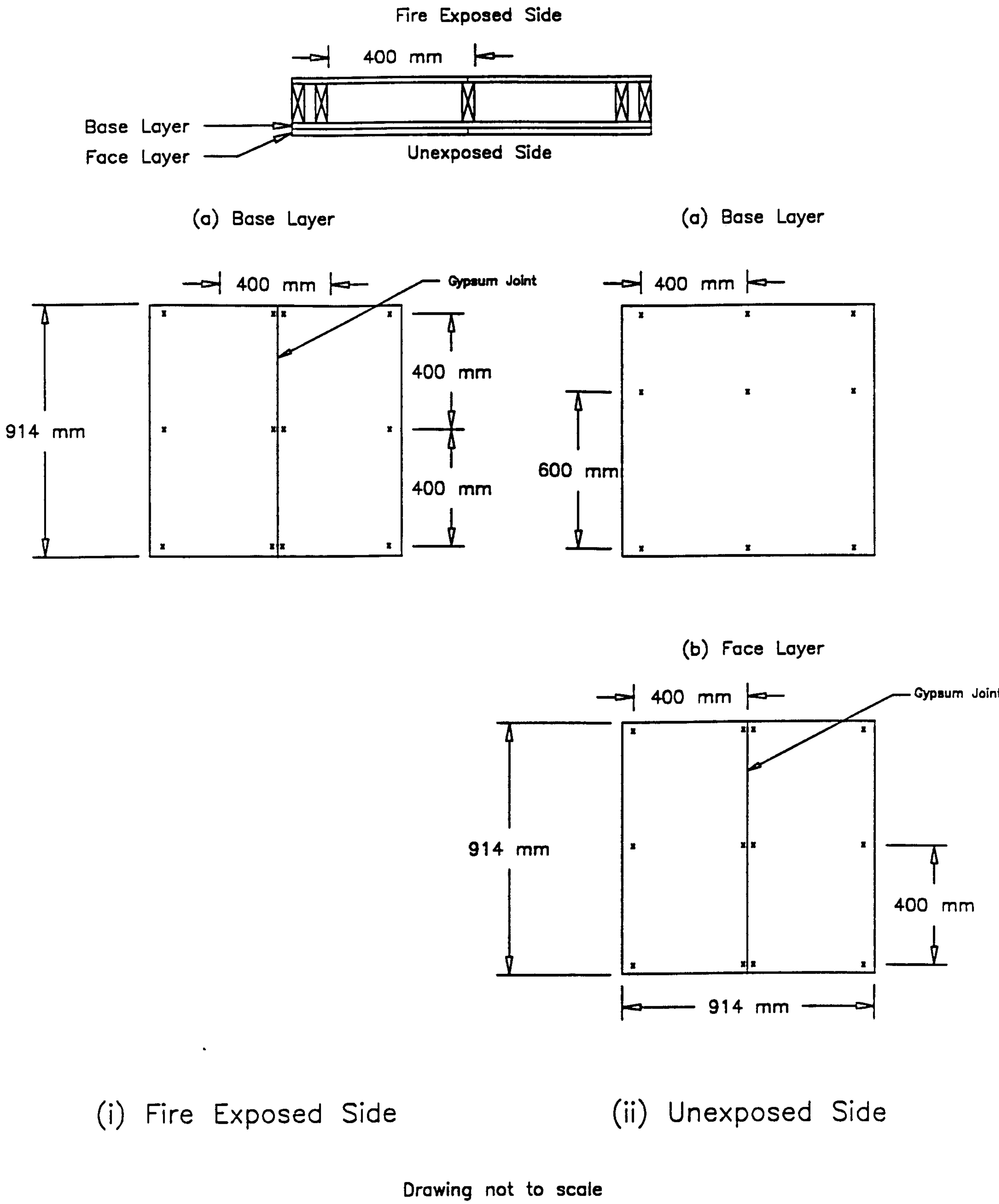


Figure 53. Screw Locations For Wood Stud, 1x2 Gypsum Layers, Small-Scale Assemblies

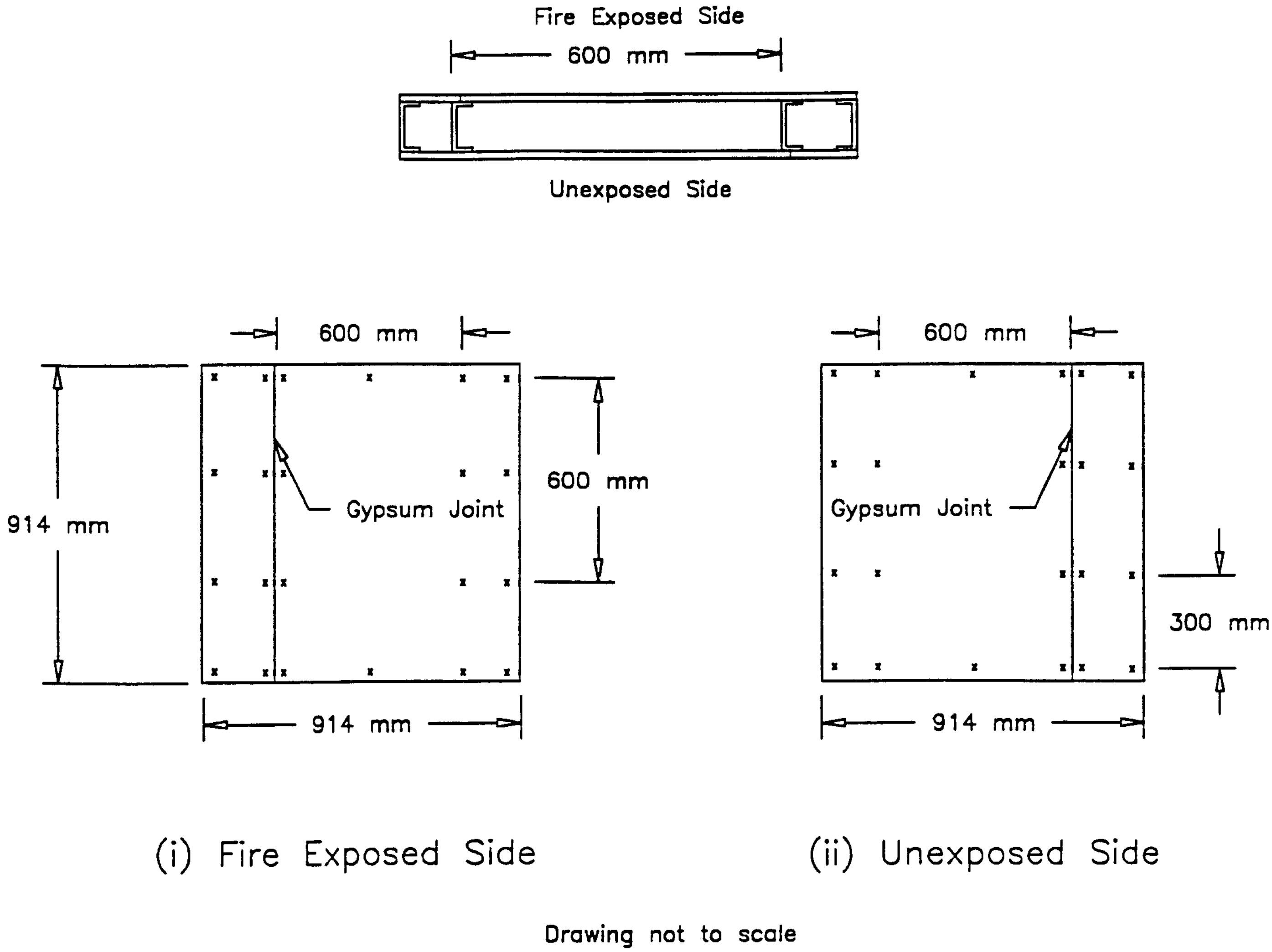


Figure 54. Screw Locations For Steel Stud, 1x1 Gypsum Layers, Small-Scale Assemblies

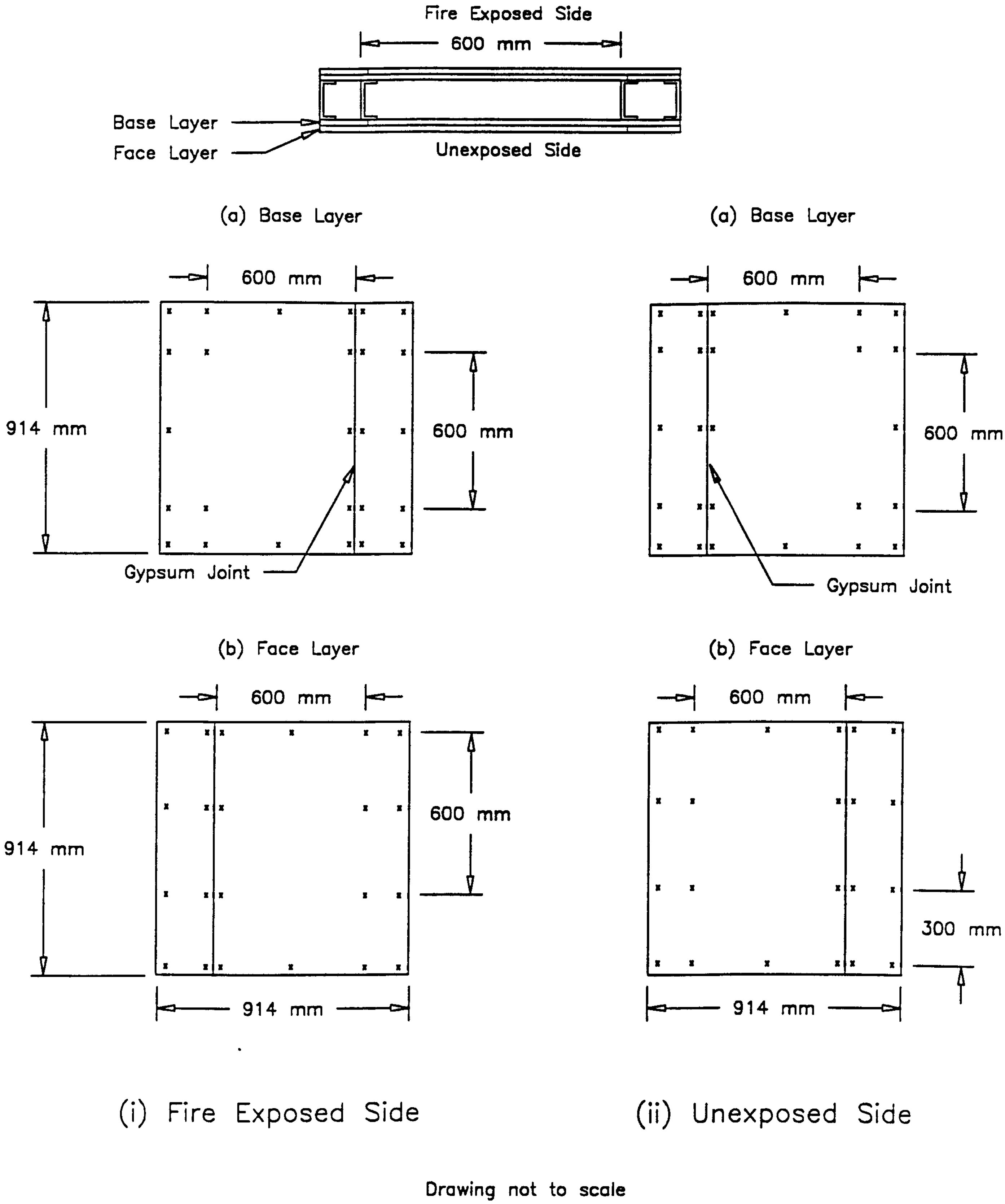


Figure 55. Screw Locations For Steel Stud, 2x2 Gypsum Layers, Small-Scale Assemblies

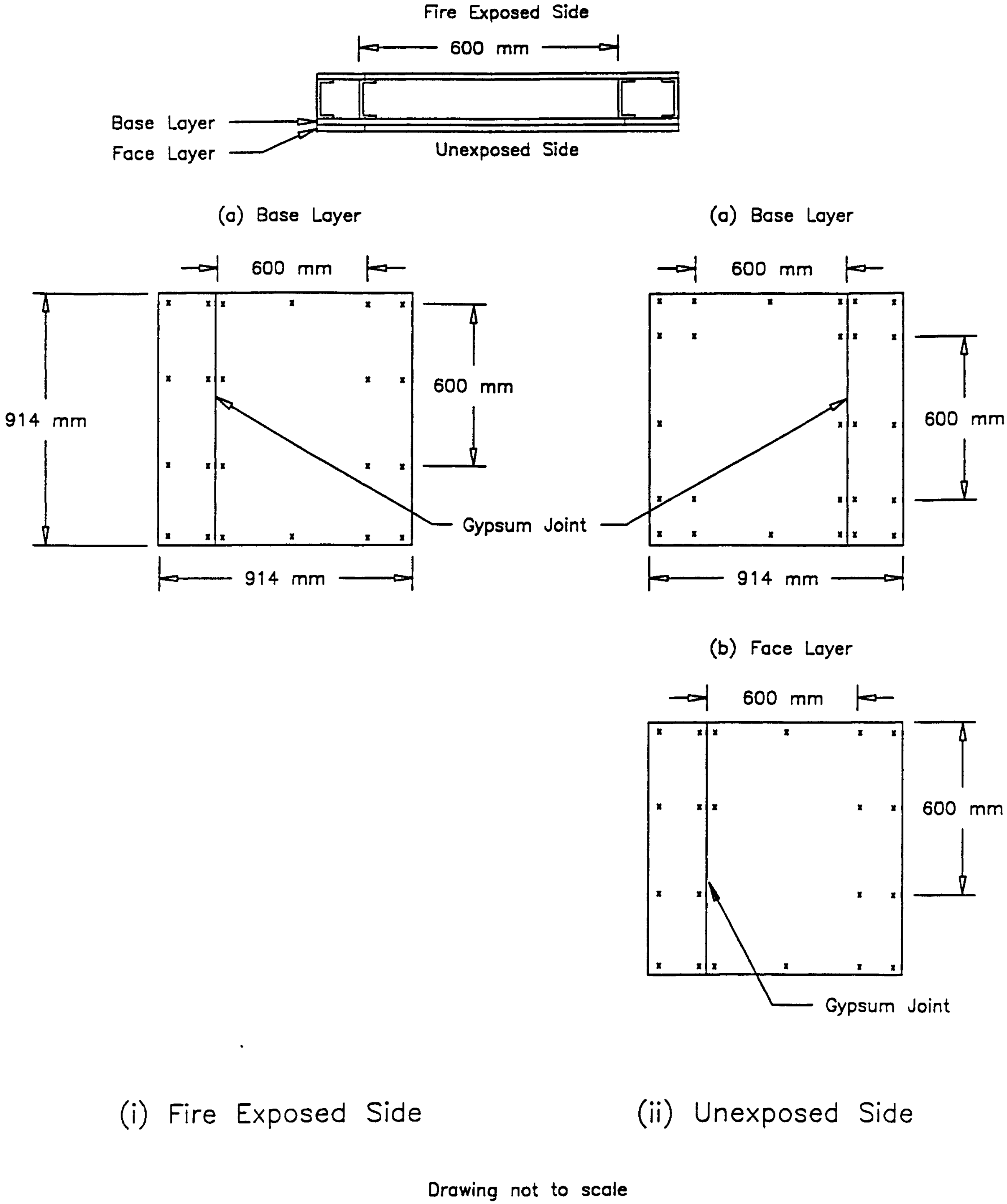


Figure 56. Screw Locations For Steel Stud, 1x2 Gypsum Layers, Small-Scale Assemblies

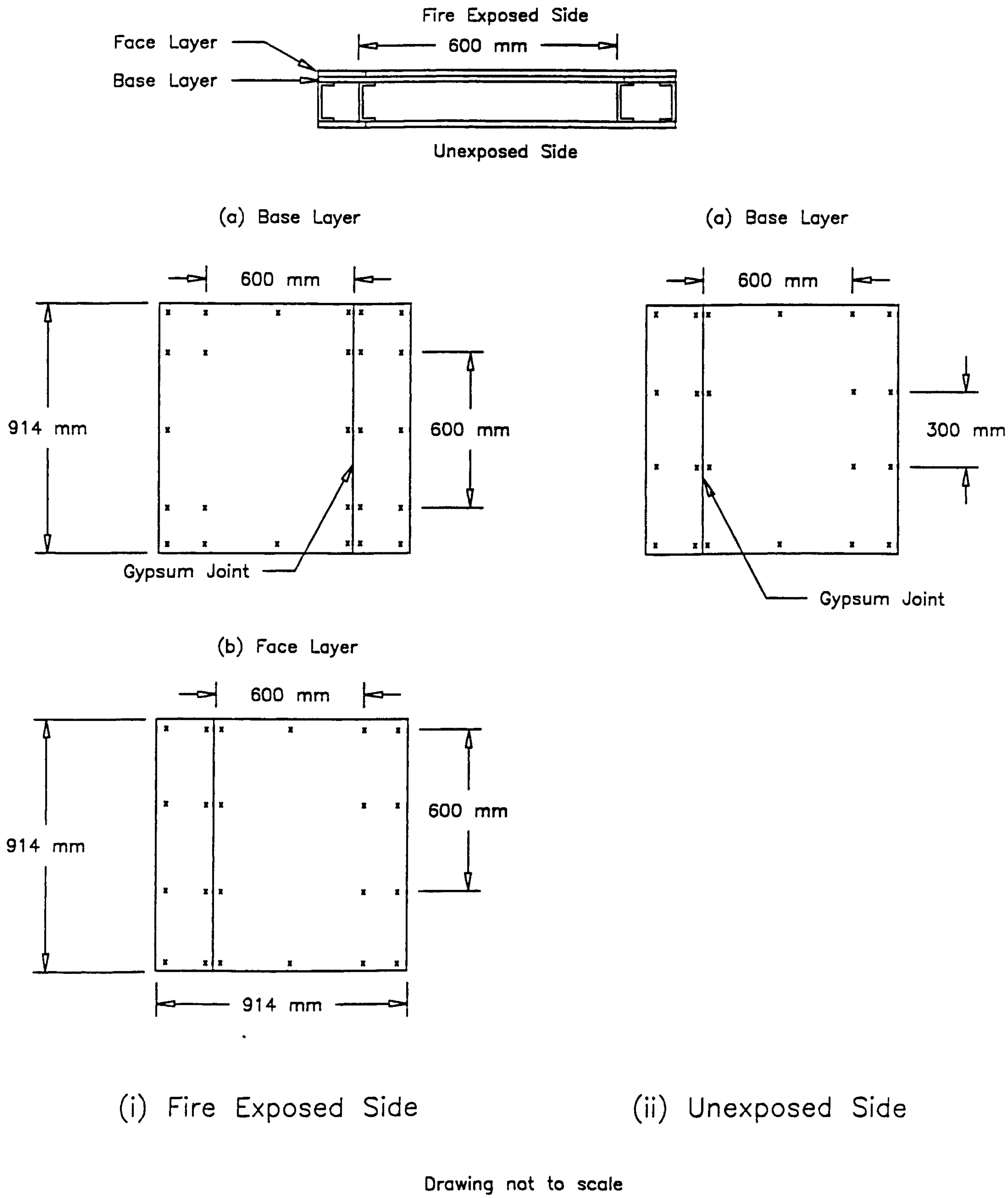
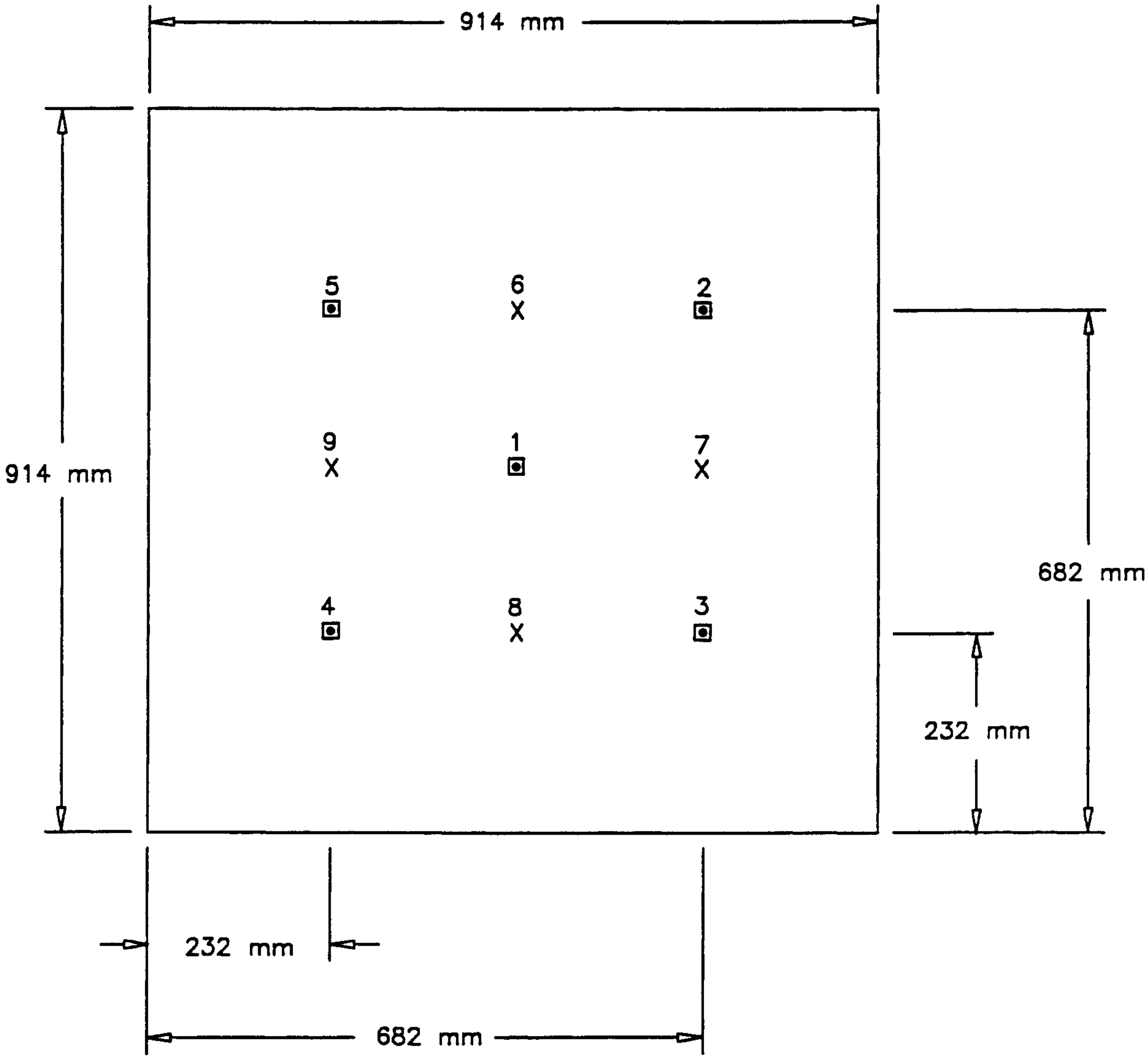


Figure 57. Screw Locations For Steel Stud, 2x1 Gypsum Layers, Small-Scale Assemblies



▣ Thermocouple Under Std. ULC/S101 Insulated Pad
x Bare Thermocouple

Drawing not to scale

Figure 58. Thermocouple Locations on Unexposed Surface of All Small-Scale Tests

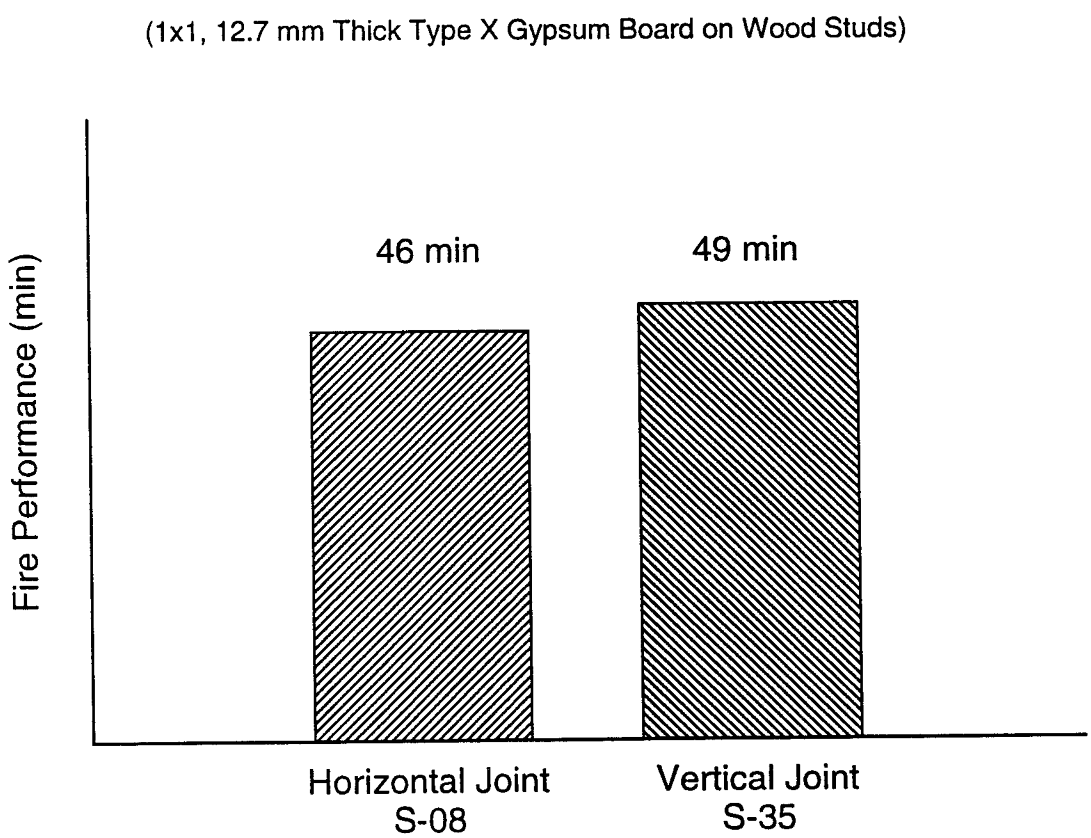


Figure 59. Effect of Gypsum Board Application Orientation

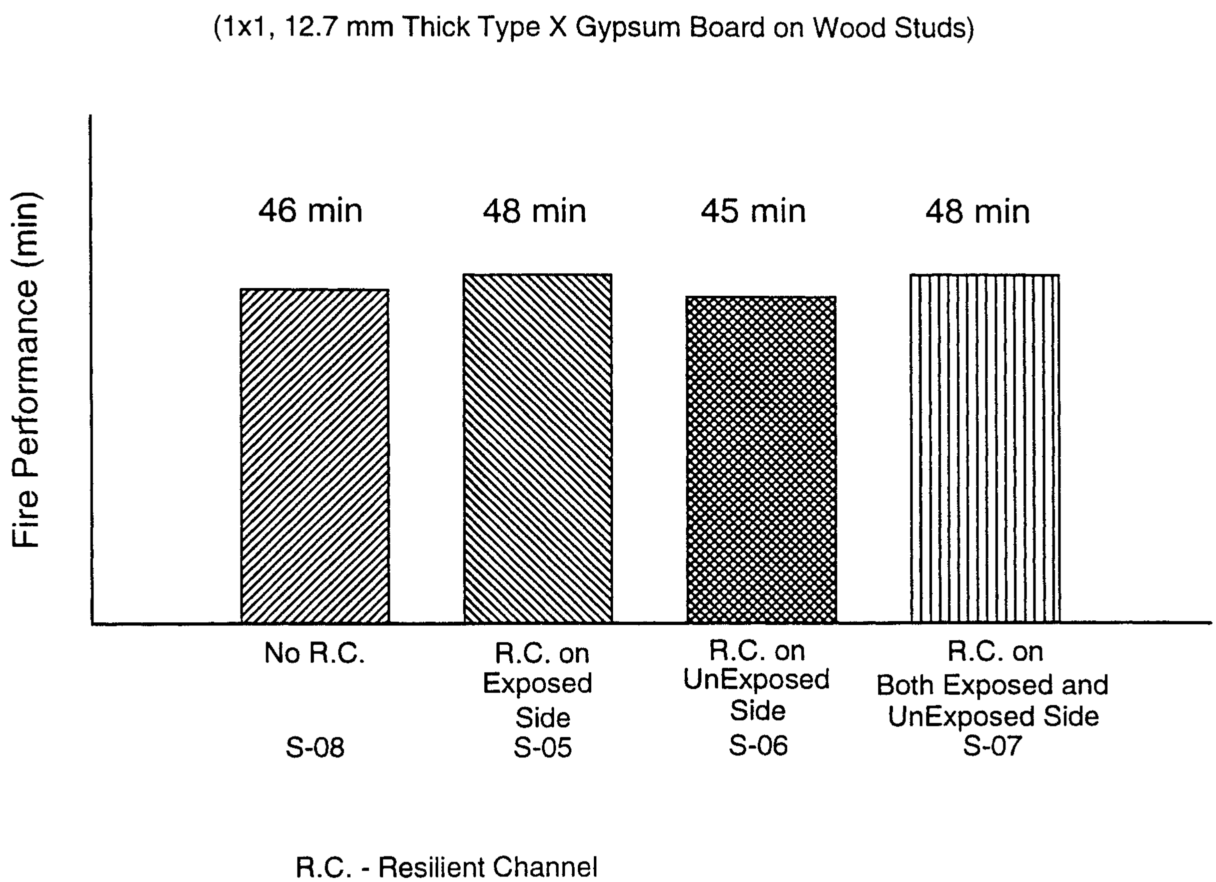
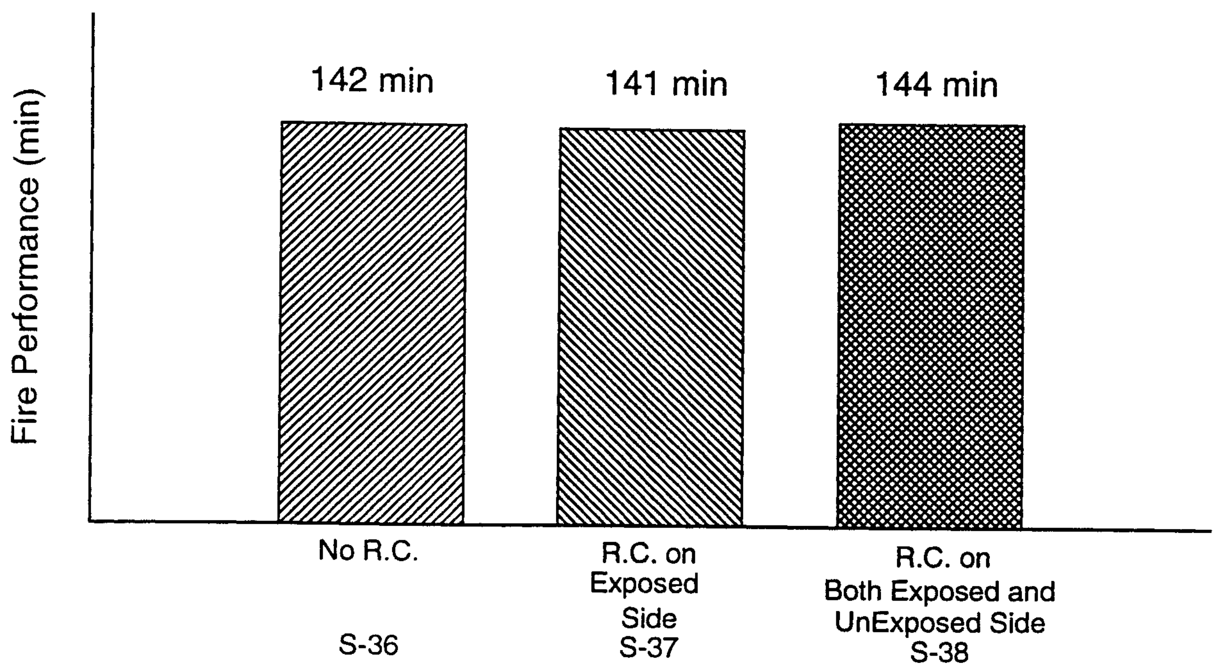


Figure 60. Effect of Resilient Channel Installation on the Fire Performance of (1x1) Assemblies

(2x2, 12.7 mm Thick Type X Gypsum Board on Wood Studs)



R.C. - Resilient Channel

Figure 61. Effect of Resilient Channel Installation on the Fire Performance of (2x2) Assemblies

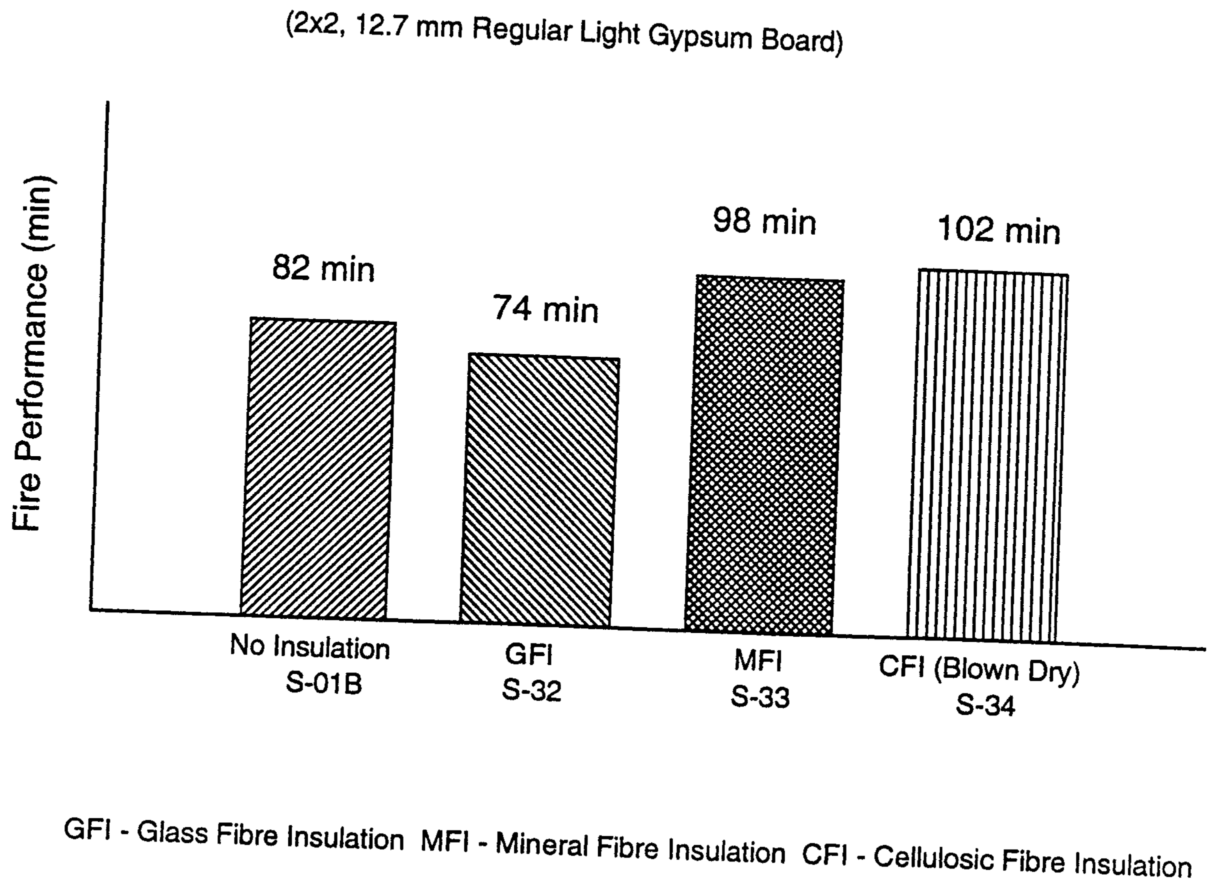


Figure 62. Effect of Insulation on the Fire Performance of (2x2) Assemblies

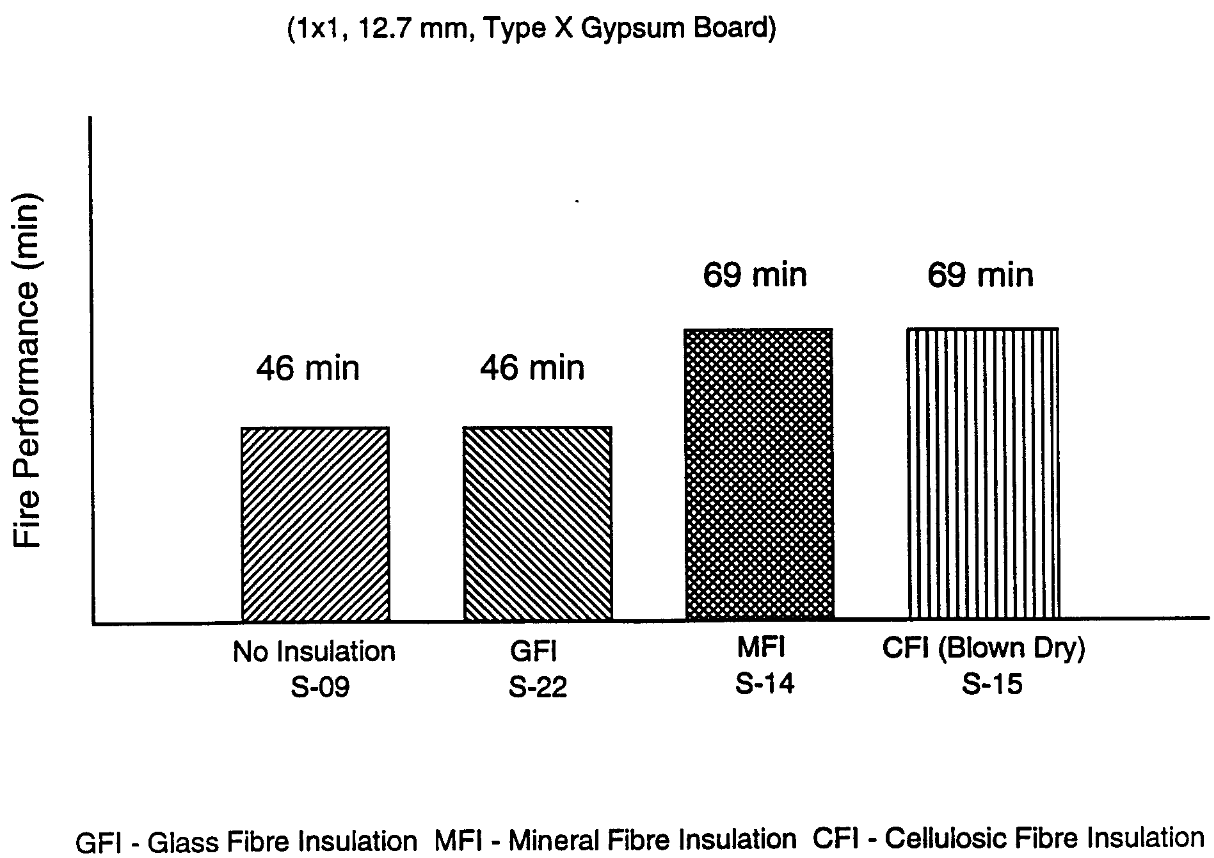
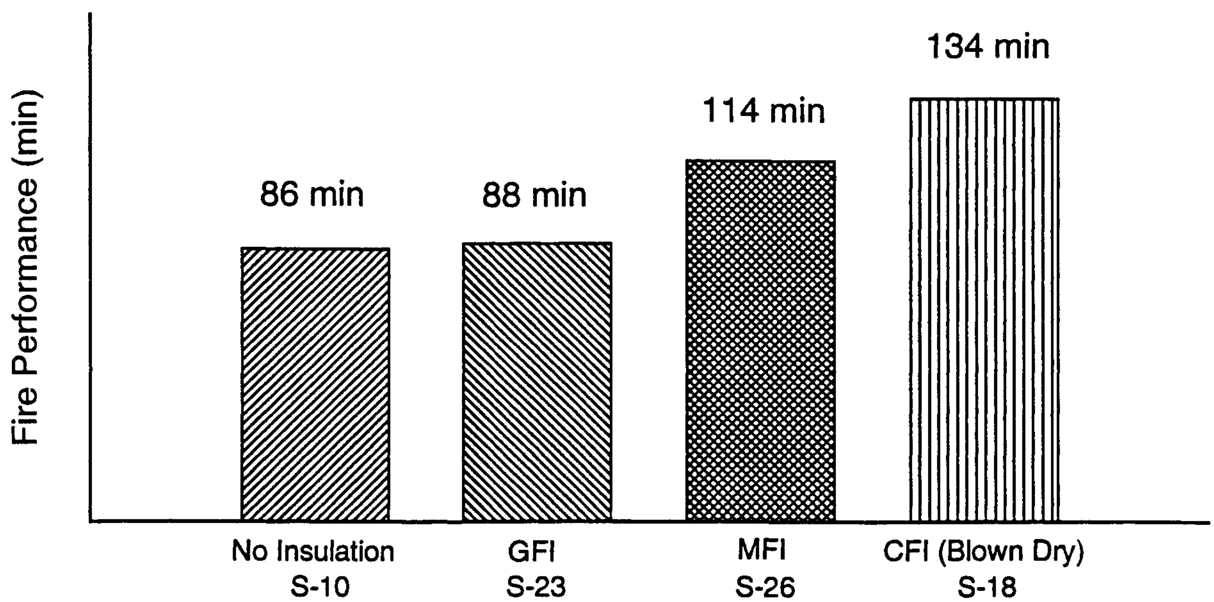


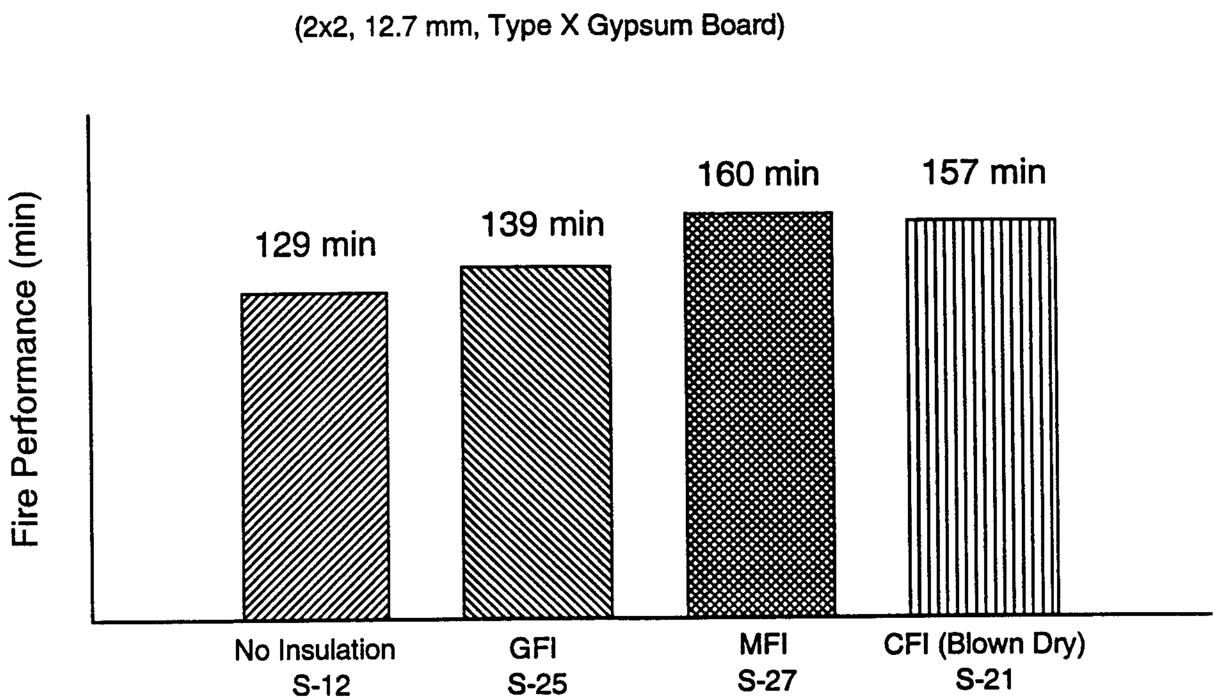
Figure 63. Effect of Insulation on the Fire Performance of (1x1) Assemblies

(1x2, 12.7 mm, Type X Gypsum Board)



GFI - Glass Fibre Insulation MFI - Mineral Fibre Insulation CFI - Cellulosic Fibre Insulation

Figure 64. Effect of Insulation on the Fire Performance of (1x2) Assemblies



GFI - Glass Fibre Insulation MFI - Mineral Fibre Insulation CFI - Cellulosic Fibre Insulation

Figure 65. Effect of Insulation on The Fire Performance of (2x2) Assemblies

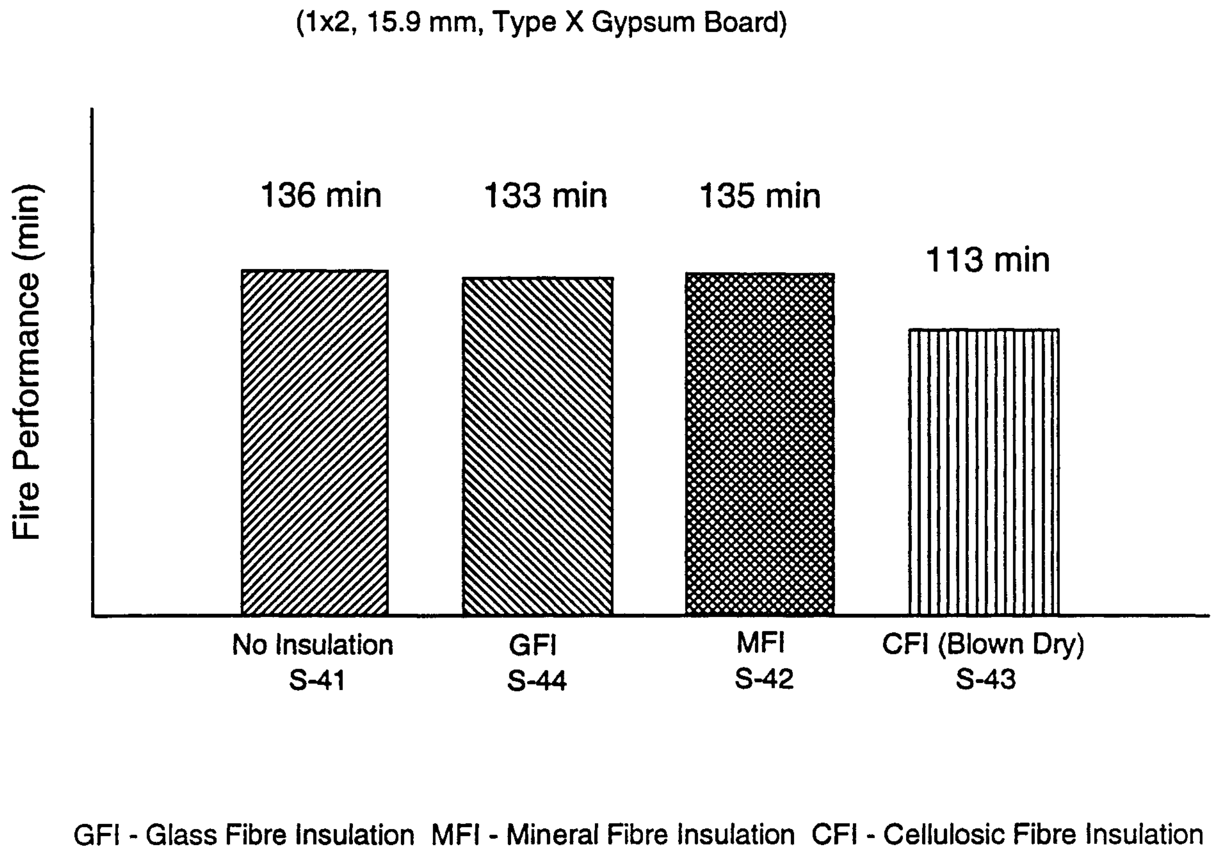


Figure 66. Effect of Insulation on the Fire Performance of 1x2, 15.9 mm Thick Gypsum Board Assemblies

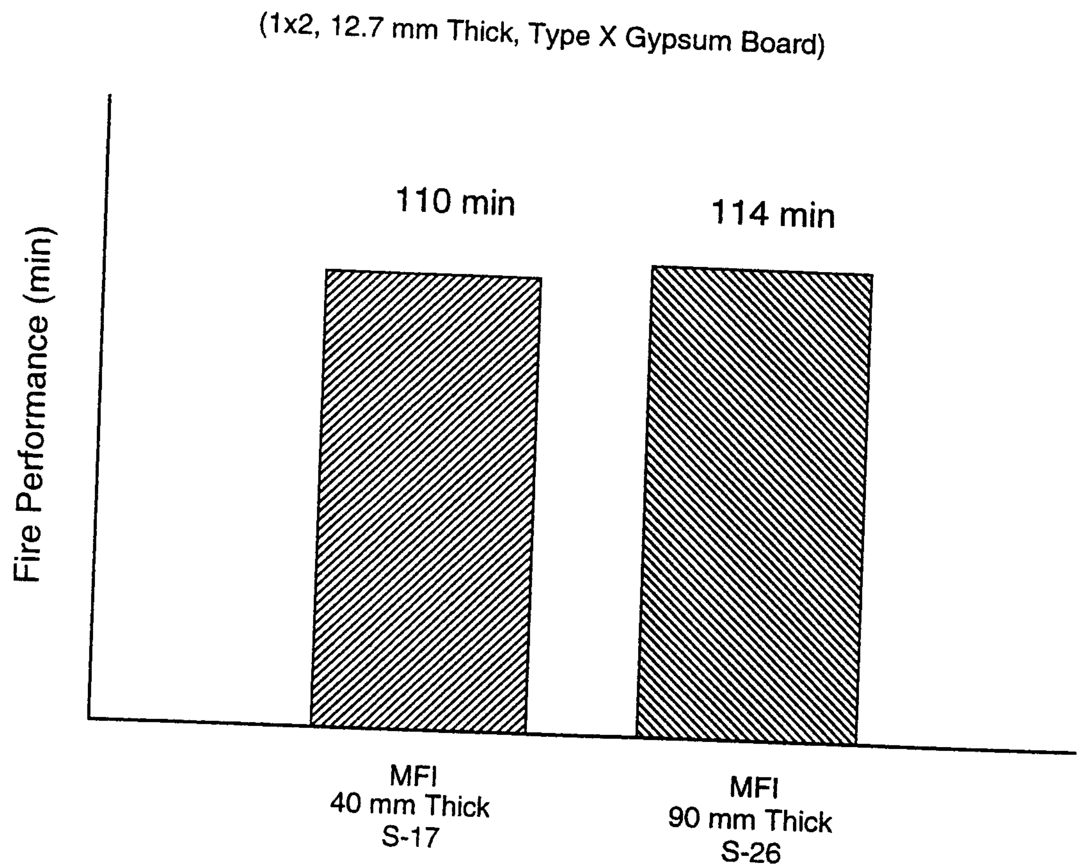


Figure 67. Effect of Mineral Fibre Insulation Thickness on the Fire Performance of 1x2 Gypsum Board Assemblies

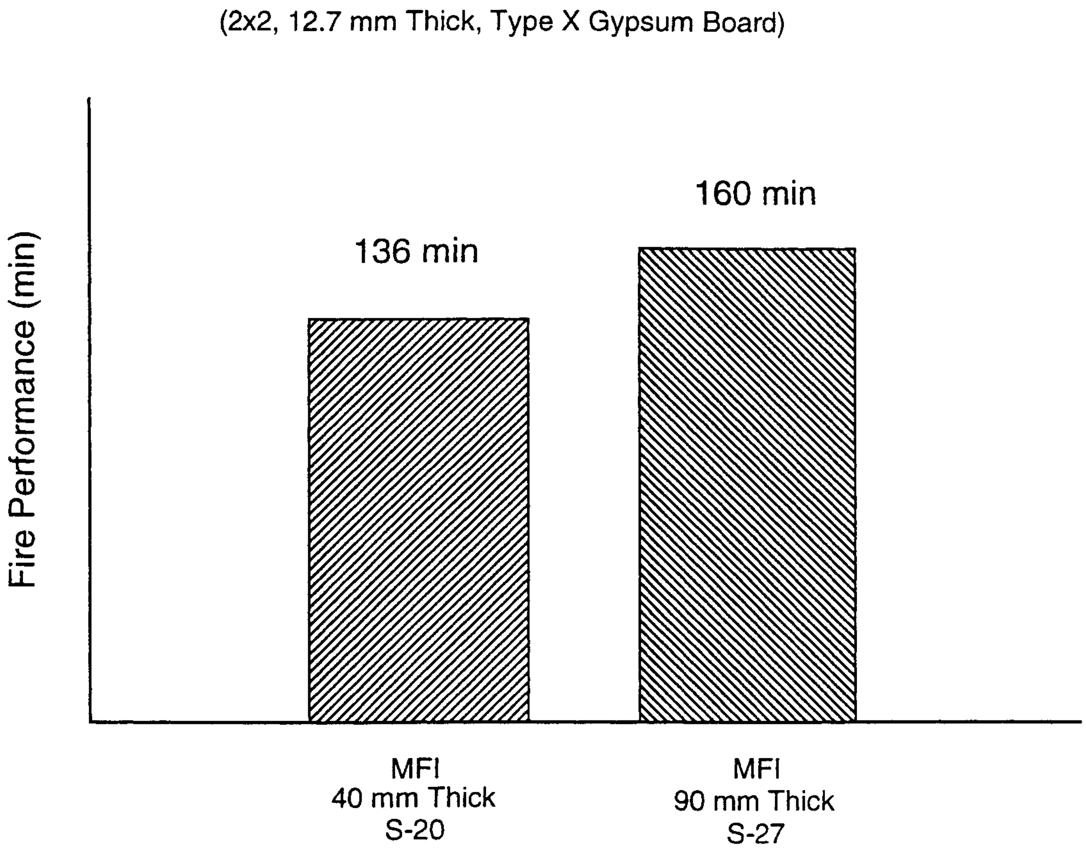


Figure 68. Effect of Mineral Fibre Insulation Thickness on the Fire Performance of 2x2 Gypsum Board Assemblies

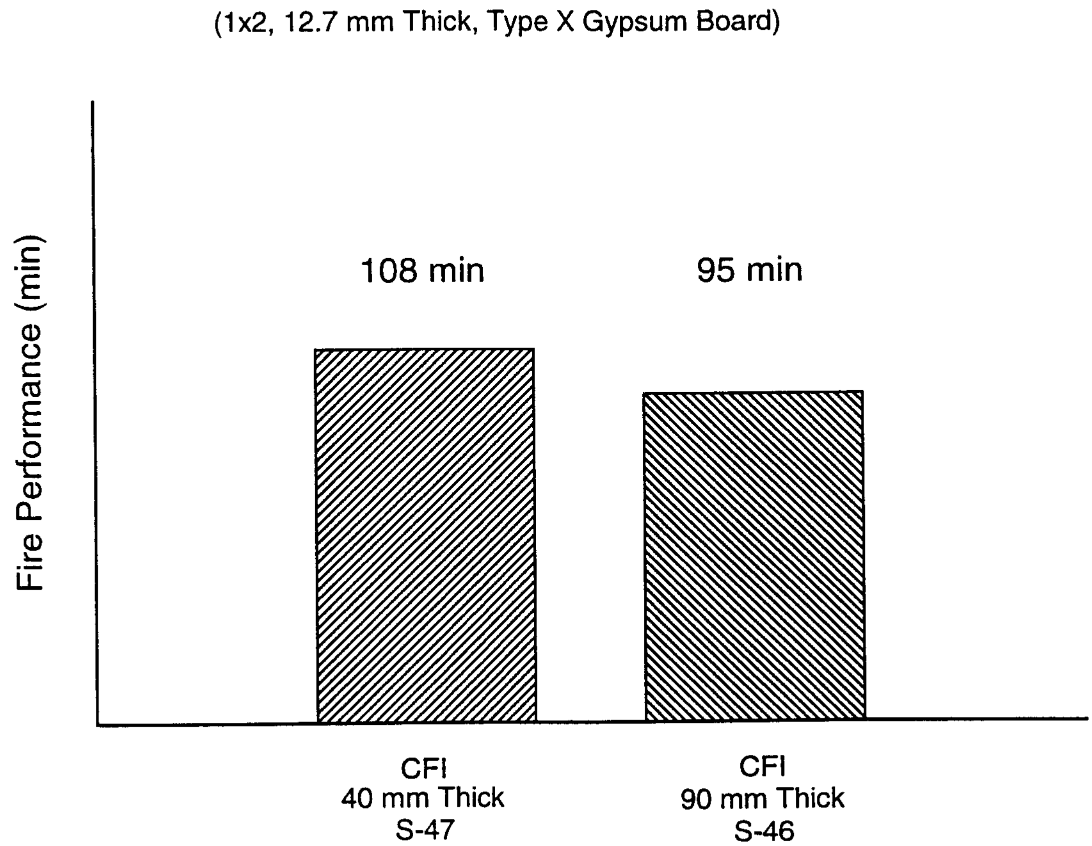


Figure 69. Effect of Cellulosic Fibre Insulation Thickness (Wet Sprayed) On the Fire Performance of 1x2 Gypsum Board Assemblies

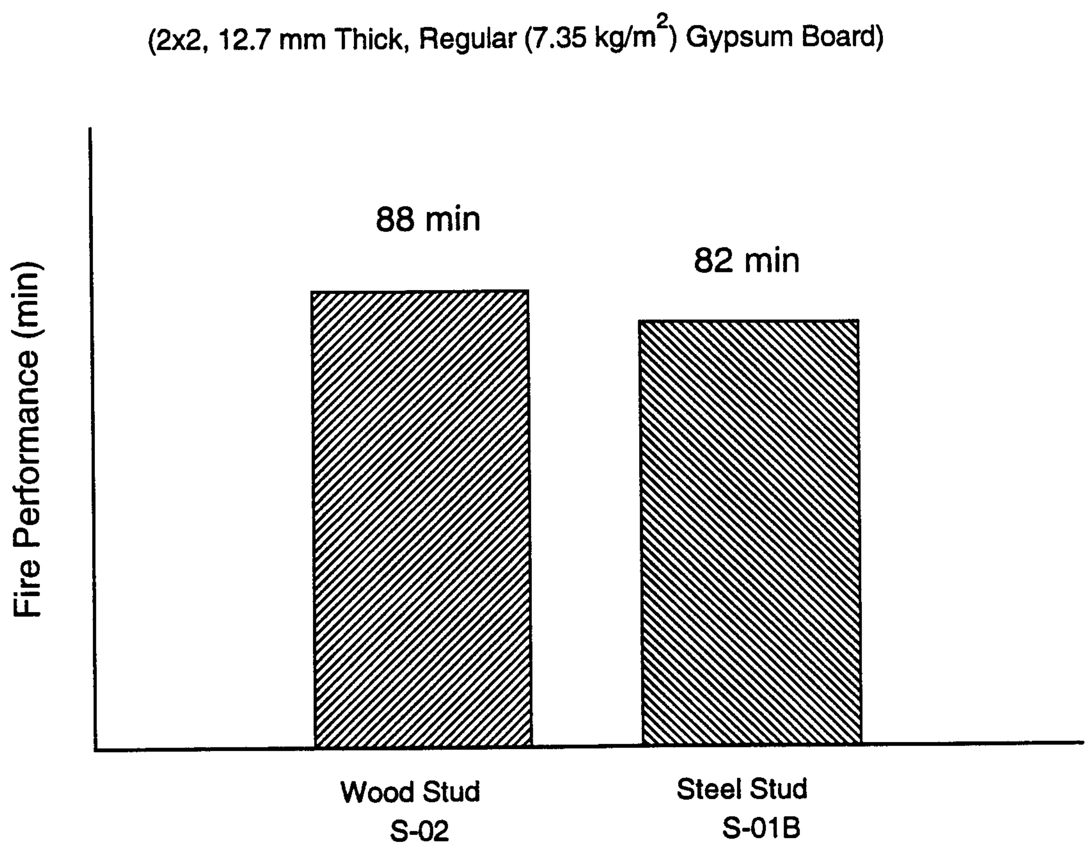


Figure 70. Effect of Stud Type on the Fire Performance of Non-insulated Double Layer Regular Gypsum Board Assemblies

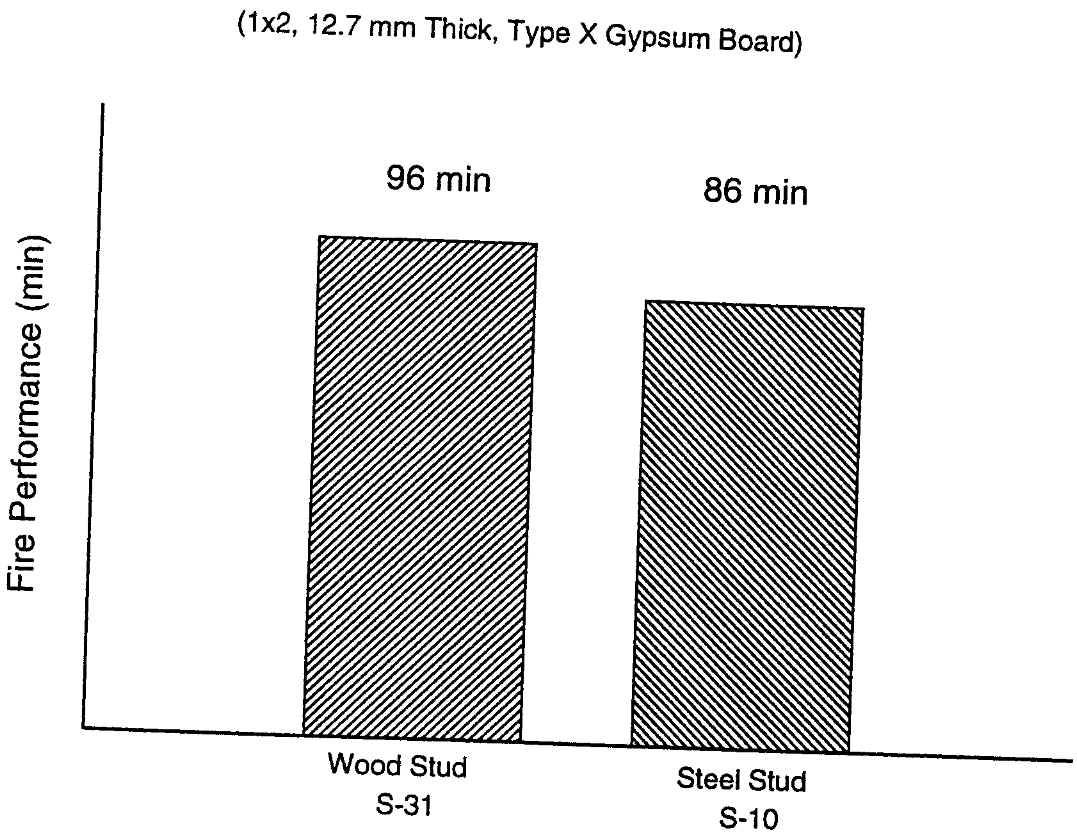


Figure 71. Effect of Stud Type on the Fire Performance of Non-insulated 1x2 Type X Gypsum Board Assemblies

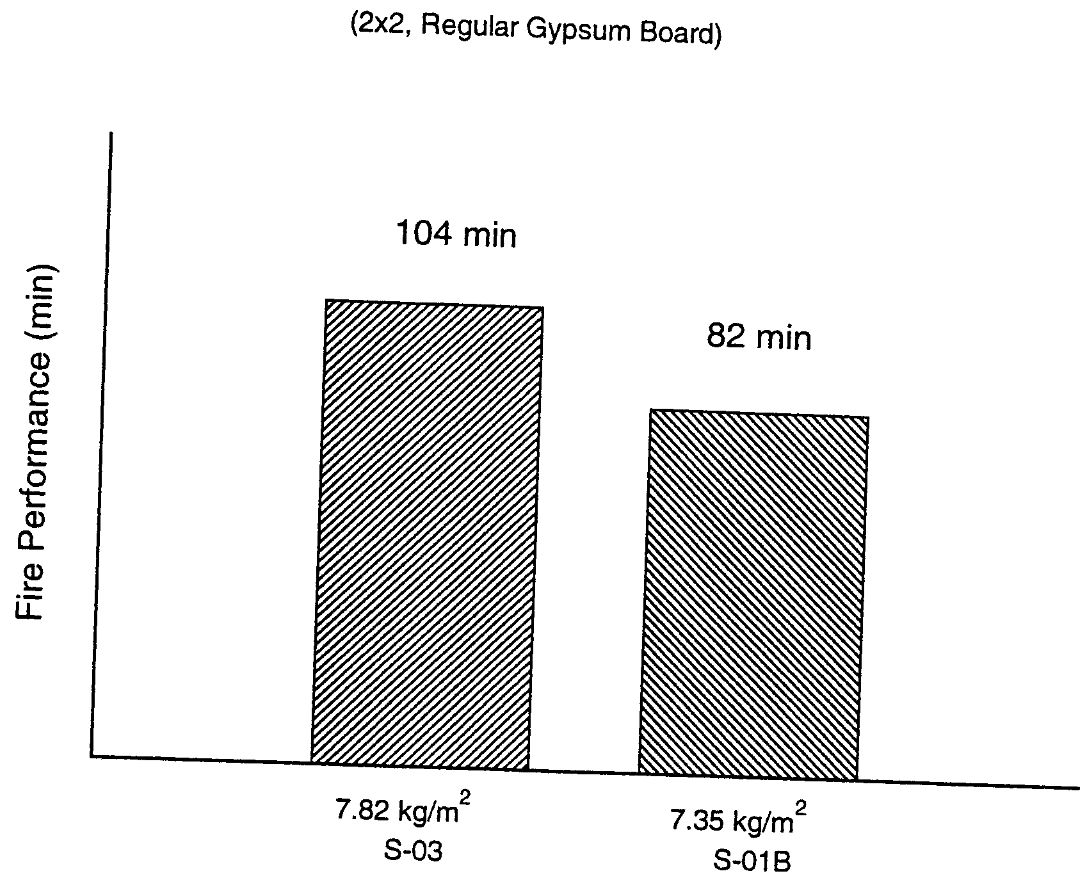


Figure 72. Effect of Different Mass/Unit Area of Regular Gypsum Board on The Fire Performance of Assemblies

(2x2, 12.7 mm Thick, Regular (7.35 and 7.28 kg/m^2) Gypsum Board)

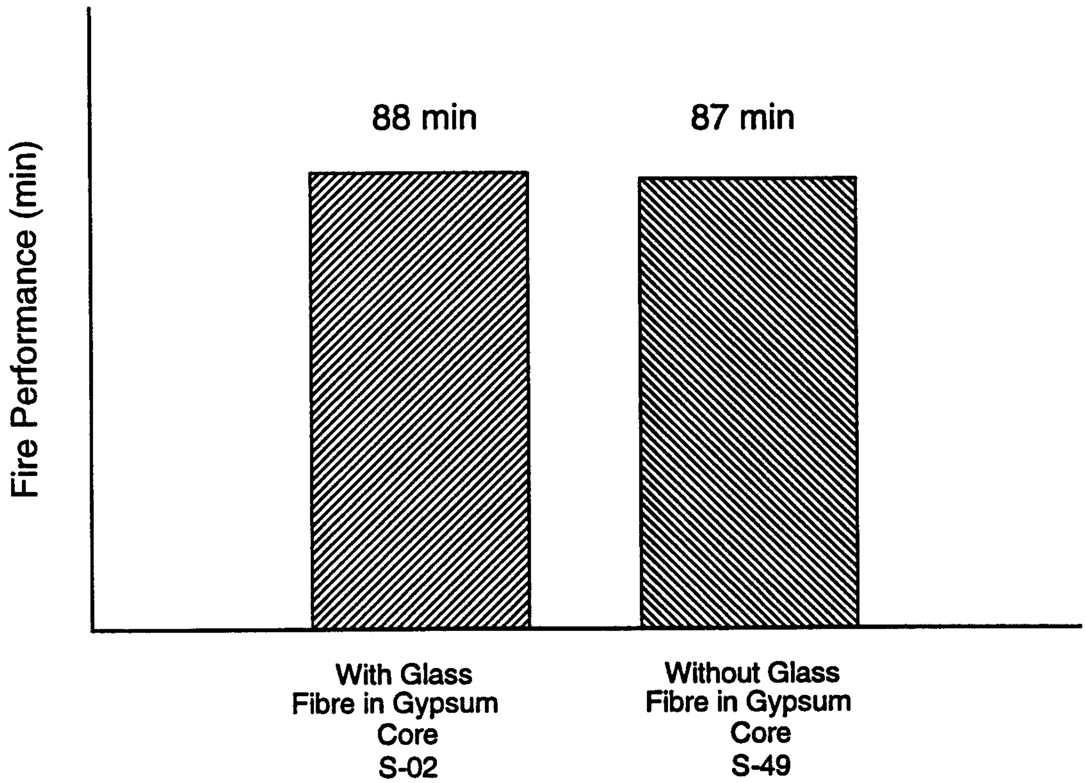


Figure 73. Effect of Glass Fibre in Gypsum Board Core on the Fire Performance of Assemblies

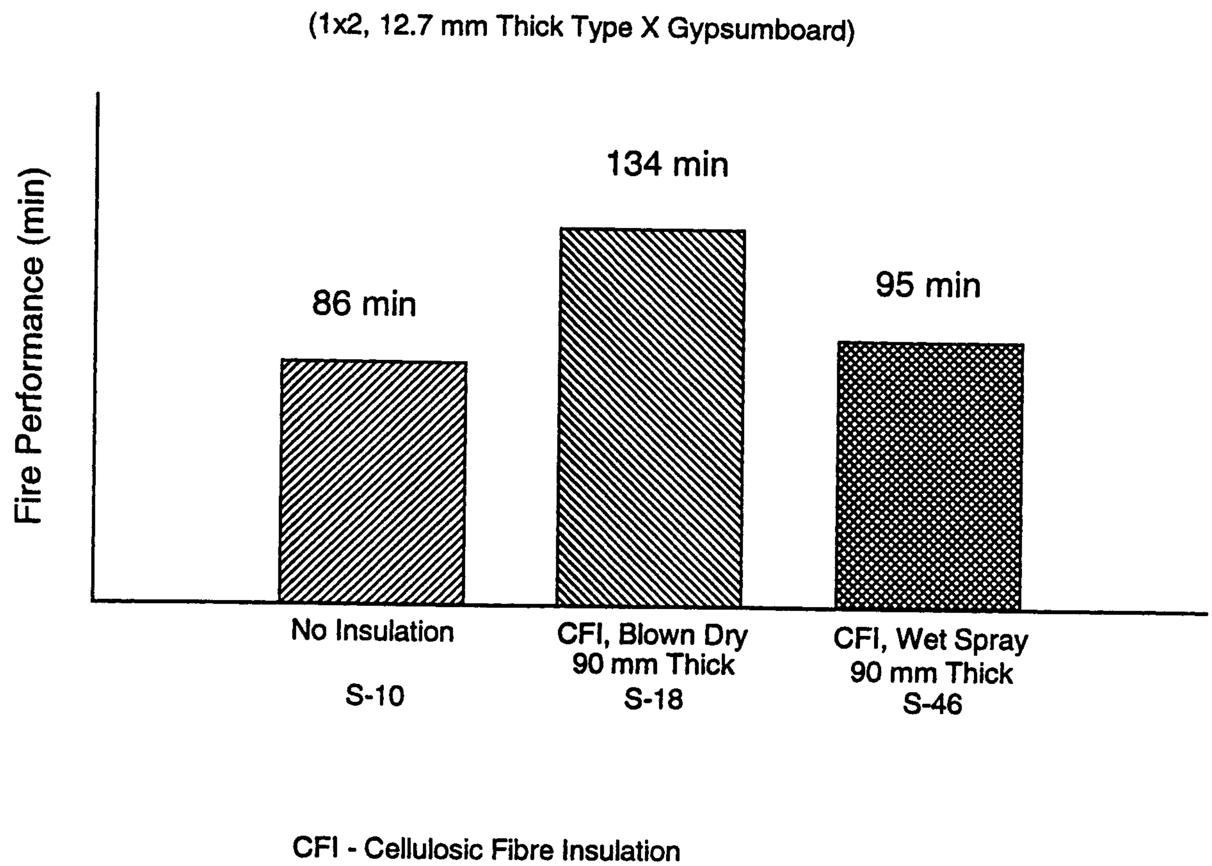


Figure 74. Effect of Application Methods of Cellulosic Insulation Fibre on Fire Performance of Small-Scale Assemblies

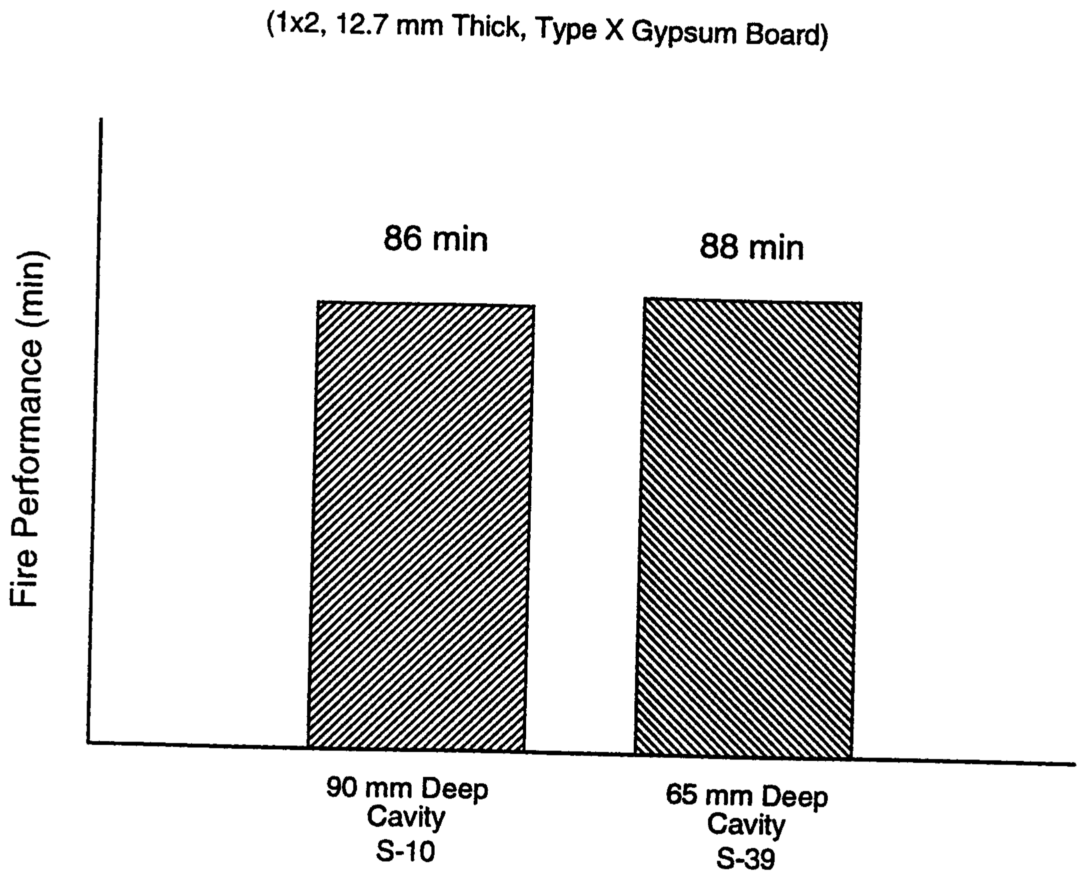


Figure 75. Effect of Cavity Depth On The Fire Performance Of 1x2 Gypsum Board Assemblies