FEASIBILITY STUDY

Storm Shelters In All
New Construction for Above-Grade
Single Family Housing

CHAPTER 195, SEC. 3
1987 MINNESOTA LAWS

DEPARTMENT OF ADMINISTRATION
BUILDING CODES AND STANDARDS DIVISION

JANUARY 1988

This Storm Shelter Feasibility Study is submitted for Legislative Review pursuant to Minnesota Laws 1987 Chapter 195, Section 3.

Respectfully submitted,

Sandra J. Hale

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Commissioner

SJH:c

Enclosure

INTRODUCTION

This report is in fullfillment of the legislative directive contained in Laws of Minnesota 198C Chapter 195 Section 3 as follows:

Sec. 3 (FEASIBILITY STUDY.)

The commissioner of administration shall conduct a study to determine the feasibility of requiring emergency storm shelters in all new construction for above-grade single-family housing and shall submit the study to the legislature by January 15, 1988.

Minnesota Laws Chapter 195 requires storm shelters in manufactured home parks licensed after March 1, 1988. This feasibility study was requested to assist in determining if storm shelters should also be required in new above grade single family housing (constructed without the protection provided by a full depth basement).

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Note: Information contained in the Text, and the Shelter Module Concept described in this study, was taken from a Federal Emergency Management Publication titled Wind Resistant Design Concepts for Residences, July 1975.

1. <u>EXTENT OF THE PROBLEM.</u>

a. THE PROBLEM - WIND

Wind is among the Nation's most severe natural hazards in terms both of lives lost or endangered and of property losses. If fire is excluded as a natural hazard, then wind is first-ranked.

Statistics for severe winds, and tornadoes are compiled separately for the particular types of storms. These records are helpful, because some characteristics associated with the various types of storms differ in their effects on buildings.

In some cases, there is little need to consider the causal nature of the wind, as in improving building resistance to extreme-wind loadings in general.

In other cases, damage-producing effects other than wind in the storms are of greater concern. Flying debris in tornadoes is an example.

These aspects are among many which suggest that protection of people and property in extreme-wind conditions is a consideration broad in scope, and often quite complex. Because life safety is a fundamental concern in extreme-wind situations, especially for tornadoes, recommendations often go beyond the requirements of construction codes which normally set minimum standards.

Contrary to popular belief, tornadic winds are not so severe that nothing can be done to protect lives. Neither is the backyard storm cellar the only answer - although the storm shelter is a safe place to be during a passing tornado. A weakness of the backyard shelter is that late arrivals sometimes are exposed to unnecessary hazards while getting to the shelter. Construction for an entire house strong enough to resist the forces induced by tornadic winds is possible, but frequently is infeasible due to cost or functional limitations.

Accordingly, there are many degrees of construction strength in buildings - degrees ranging from near-absolute safety for the occupants to no more than code-required construction which often provides little safety in extreme-wind situations. In practice, even code requirements too often are ignored in the mistaken belief they are excessive.

Severe winds can damage and destroy roofs, toss mobile homes off their pier foundations, and tear light-framed homes apart. Architects, builders, and homeowners weigh such risks against the cost of hazard-reducing construction and other factors; or they ignore the risk, and therefore occasionally suffer or see others suffer the consequences.

Sometimes people seek security through better, stronger construction but do not have sufficient information on how to proceed and cannot get the needed architectural or engineering guidance. This is a problem especially in residential construction.

Two basic methods seem available. One would be to design the entire structure to resist the wind forces. The other is to provide an interior module for the purpose of occupant protection. Since the interior module would be the least costly we have based our estimated costs on that method.

2. DAMAGE AND CASUALTY ASPECTS.

Hazards caused by extreme winds are examined in two contexts:

Protection of property, and occupant safety.

Hazard-reduction measures often must be different for the two objectives. This is true particularly in considering the effects of tornadic winds.

The extent of building damage caused by straight winds is closely related to their velocity. As wind intensity builds, not only can more severe damage be expected, but forces upon structures tend to change characteristics. For example, additional loadings caused by flying debris may be superimposed upon straight-wind pressure. Occupant safety becomes a concern when parts of a building are torn loose in windstorms, or when debris from other sources impacts upon a building. This can occur before building structural failure and may occur even without such failure.

a. STRAIGHT WINDS

All winds typically create pressures (forces or loadings upon buildings and component parts. These pressures occur on windward, leeward (downwind), and side walls, and on roofs. The pressures may be inward-acting (positive) or outward-acting (negative or suction), an aspect which depends upon pattern of air flow around the building as well as building configuration, such as shape, height, and roof slope. The magnitudes of the pressures also may be different on the various surfaces.

Physical characteristics of air flow around buildings result in larger pressures (called localized pressures) at edges and corners, such as wall corners, roof ridges, eaves, and overhangs. These localized pressures often are sufficiently greater than overall surface pressures so that they must be considered separately.

The magnitudes of these wind pressures are predictable for specified velocities, as are their distribution on buildings. Once magnitudes and distribution are known, the required strength of construction-bracing, nailing, or bolts-can be established.

b. EXTREME WINDS

As winds increase in velocity, another effect becomes increasingly significant; namely the impact hazard of airborne debris. Loose boards, torn sheet metal, tree limbs, and many objects lying around residences become potential flying missiles. Large, flat sheets of plywood and light sheet metal have aerodynamic characteristics which make them especially likely to become airborne. Roof gravel also may be picked up and hurled to break window glass. Wind velocities at which debris becomes airborne vary with the aerodynamic characteristics. This effect is unlikely to be hazardous to people when wind velocities are less than 50 to 60 mph.

Extreme winds become threats to safety and cause major damage to buildings through the effects of pressure-loading and impact-loading occuring simultaneously. These effects become ever-more-displacement and even total collapse are the ultimate damaging effects of extreme winds.

c. TORNADIC WINDS

Tornadic winds cause loading pressures on buildings similar to extreme winds, but there are two important differences: Tornadic winds blowing against a building may rapidly change directions and will have continually varying velocities because of their rotational nature. Also, a tornado will pass over a building in a relatively short time as compared to extreme straight winds.

Most buildings are not designed to withstand the extreme loadings caused by tornadic winds. Some kind of failure in standard construction normally is expected - severe tearing, displacement, or even total destruction. The extent of damage is related to many factors - including direction of the wind, strength of construction of the whole and parts of the building, and materials of construction.

Any type of failure, partial or total, is hazardous to occupants. Collapse, displacement, and penetration of flying debris through walls, roofs, or openings all can cause casualties.

d. OCCUPANT SAFETY AND PROTECTION OF PROPERTY

Safety of building occupants must be considered in terms of -

Building collapse.
Building displacement.
Penetration of airborne debris into the occupied space.

Property damage may be reduced by providing bracing to resist building collapse and connections (joints) among materials in construction which are as strong as the materials.

3. EXTREME WIND AND TORNADO FORCES ON BUILDINGS.

a. WIND-INDUCED FORCES

For buildings, the wind effects of concern are the pressures (forces or loadings) on surfaces such as walls, roofs, and overhangs. Construction materials and methods of assembly are selected to resist these forces. Accordingly, the nature and magnitudes of the forces due is extreme winds which load a building must be established as a first step in protective construction.

The loading for each building surface usually is given in pressure (lb. per sq. ft. of surface area). The magnitude of the pressure is dependent upon wind velocity and direction as well as building configuration (geometry).

Dependency of pressure magnitude upon wind velocity requires that a wind condition be assumed. Maximum velocity, which will produce the worst loading condition, is used. The maximum velocity necessarily must be predicted, and this prediction is based upon past wind history for a particular geographic location.

The pressure magnitude resulting from a given wind condition typically will be different on wind-ward, side, and leeward walls, and roof surface of a building. Because wind direction can be expected to change, surface pressure may be different on a wall or roof as the same wind velocity acts from a different direction. The pressure may be inward-acting on a surface when the wind is from one direction and change to outward-acting when the same wind is from another direction. The maximum pressure(s), inward-acting and outward-acting, must be established for each surface, using the wind direction which produces each maximum effect.

Both maximum inward-acting and outward-acting pressures must be resisted by the materials of construction and their assembly.

Some building configuration characteristics which affect pressure are sufficiently similar from building to building that pressure acting on some surfaces may be generalized in terms of wind velocity. In such cases, tables listing pressures for particular surfaces and various wind velocities may be used.

In other cases, the pressure on a surface is dependent upon building form, dimension, roof slope, or other physical features which may vary from building to building. For these, pressure is dependent upon two or more variables, and tables covering all possible conditions cannot reasonably be furnished. In this booklet, simplifying assumptions have been made for these cases so the homeowner and building may be helped toward the goal of improved, safer construction.

The accepted procedure for establishing the maximum wind velocity value uses predictions statistically derived from past wind histories.

The Minnesota State Building Code lists the average 50 year mean high wind speed at 33 feet above ground at about 70 to 80 miles per hour for various areas of the State. Which means a positive pressure of 14 to 18 pounds per square feet acting inward.

b. TORNADO-INDUCED FORCES

Buildings subjected to tornadoes may be loaded by forces which are additional to the forces of straight winds. Three types of tornado loadings are identified.

Wind pressure.
Impact of flying debris.
Atmospheric pressure differential.

Magnitudes of these loadings are more difficult to establish than are those for straight winds. Information on tornado characteristics is much less precise. A few observations, however, show that tornadic-wind speeds vary from storm to storm just as do straight-wind velocities.

(1.) WIND PRESSURE Because wind speed directly influences all three loading types listed above, information about tornado-wind velocities is needed for design. One researcher (T.T. Fujita) has complied data on tornadoes occurring in 1971 and 1972, with classification according to wind velocity estimates and frequency of occurence.

It is noteworthy that wind velocities of 91 percent of all tornadoes in the 2-year period were estimated at less than 158 mph; and of 97 percent, less than 207 mph. From these and other studies, the conclusion is that the wind velocities of most tornadoes are in the same range as those of severe hurricans, and usually are not in the devastating range often suggested for these storms. Therefore, buildings designed to resist tornadic-wind forces and associated impacts of flying debris in the 200 mph range should provide safety more than 95 percent of the time.

If greater certainty of occupant safety is desired, a wind velocity of 260 mph may be taken as the design basis - with reasonable assurance that a building so designed will be 99 percent safe.

A residence designed to withstand winds up to 112 mph should be safe in more than 65 percent of all tornadoes.

Because these percentages are statistically derived from limited data, the conclusions cannot be taken as certain. Nonetheless, they do furnish a rational design basis for tornadoes.

(2.) IMPACT OF FLYING DEBRIS Debris impact upon a building during a tornado is highly unpredictable - both in quantity of material and intensity of impact. This type of loading is dependent not only upon the amount of potential missile materials which may be around a building, but also upon their aerodynamic characteristics - which affect flight. None of these characteristics can be generalized due to the random nature of the materials which may be present; so the practice has been to identify a probable worst-loading condition and to use this as the design basis for impact loadings.

The suggested worst-loading condition (Mehta, Minor, and McDonald, 1974) is a 2-in. x 4-in. piece of lumber, 12 ft. long, striking end-first at 100 mph, in winds of 260 mph. This impact loading is taken as the most hazardous due to the penetration potential through walls.

Some building materials (for example, asbestos shingles, sheet metal, and plywood on wood studs with gypsum board inside finish) have little resistance to penetration under this kind of loading. Other construction (such as face brick with steel-reinforced masonry block backup, or solid masonry block with steel reinforcement) resists this kind of loading much better. Hence, the degree of occupant protection and building resistance to damage will be determined in part by the materials of construction used.

Because of the hazard posed to occupant safety, special attention must be given to impact of flying debris in tornadic winds.

(3.) ATMOSPHERIC PRESSURE DIFFERENTIAL This is another possible loading upon a building which could result from a passing tornado. Basically, it is an outward, "explosive" loading. The inner core (eye) of a tornado typically has a lower atmospheric pressure than the surrounding stable air. Air subjected to lower atmospheric pressure has greater volume than air of higher pressure. Thus, as a tornado passes over a building, the outside pressure on the building's surface is for a short time lower than the air pressure inside the building. The result is a net outward force on all surfaces as the air seeks a stable state.

Almost all buildings have some degree of natural venting (grilles, undercuts of doors - and even leakage around windows), and tornadoes do not move so quickly as to cause instantaneous loading. Therefore, atmospheric-pressure-differential loading is not believed to be a significant effect of tornadoes leading to building failure. Failures due to this effect have not been apparent to trained observers.

In general, if there are some openings in a space, so that air movement can occur between inside and outside, then atmospheric-pressure-differential loading would be unlikely. It is an unusual space that has no openings, or has openings which are air-tight.

In terms of hazard to life, tornadic forces are viewed in the following order of severity:

1. Impact of airborne debris.
2. Wind pressure.
3. Atmospheric pressure differential (unlikely).

4. CONCEPT APPLICATION.

a. RESIDENTIAL CONCEPT APPLICATION.

The residence shelter module concept aims at providing occupant safety in areas subject to tornadoes. This design concept does little to insure against reduced property damage to other portions of a residence, but does insure safety. The concept is most readily applicable in new construction.

Advantages are several. First and foremost is that protection can be excellent. Also, the shelter module is in a convenient, quickly accessible location within the residence; and the shelter module has a daily usefulness. Moreover, the protective features of this shelter module can be visually and functionally blended to fit the residence.

The concept of a residence shelter module, as suggested by E. W. Kiesling, is based upon a strengthened interior space which insures protection from the effects of extreme winds. Strengthening an entire residence to resist tornadic winds usually is impractical due to high cost and resulting appearance of the residence. The shelter module is a reasonable and possibly more acceptable alternative.

The residence shelter module is a sturdy space, such as bathroom, utility room, den, hallway, or storage space, where construction is stronger than in other portions of the residence, and is independent of them. There are many possible locations for the shelter module within a residence. Here are some guidelines for the selection:

Interior spaces are best.
Space selected should be rather small, such as bathroom, utility room, or dressing room/closet combination.
Few door openings into the space. A single door is preferred.
Construction should be independent of other portions of the residence.

Interior spaces are best, because penetration of airborne debris is less likely. Small spaces gain greater strength than larger spaces with the same construction. Economy also is a factor in making the space small. Door openings into the shelter module could be a weakness if not protected by adjoining or baffle walls, or if the door is not made heavier. Roof construction also must be sufficient to resist missile penetration. Independent construction reduces the possibility that failure of other portions of the residence will cause failure of the shelter module. For example, if the roof of the residence is torn off, this could expose occupants of the shelter module as well.

As an example, an interior bathroom is the designated shelter module in a one-story, slab-on-grade residence.

This module is designed to resist tornadic winds up to 260 mph.

Overhead construction for the shelter is independent of other framing of the residence, and is secured to walls of the module.

Two alternatives for wall construction are shown. Both will provide strength to resist penetration of flying debris. A reinforced block masonry wall is one choice; and a wood-framed system with infill of concrete grout is the other.

Additional protection for the doorway has been provided by a heavy sliding door - recessed into a pocket for improved appearance.

Venting of the shelter module is provided in a ceiling fan housing, which also provides ventilation for the bathroom.

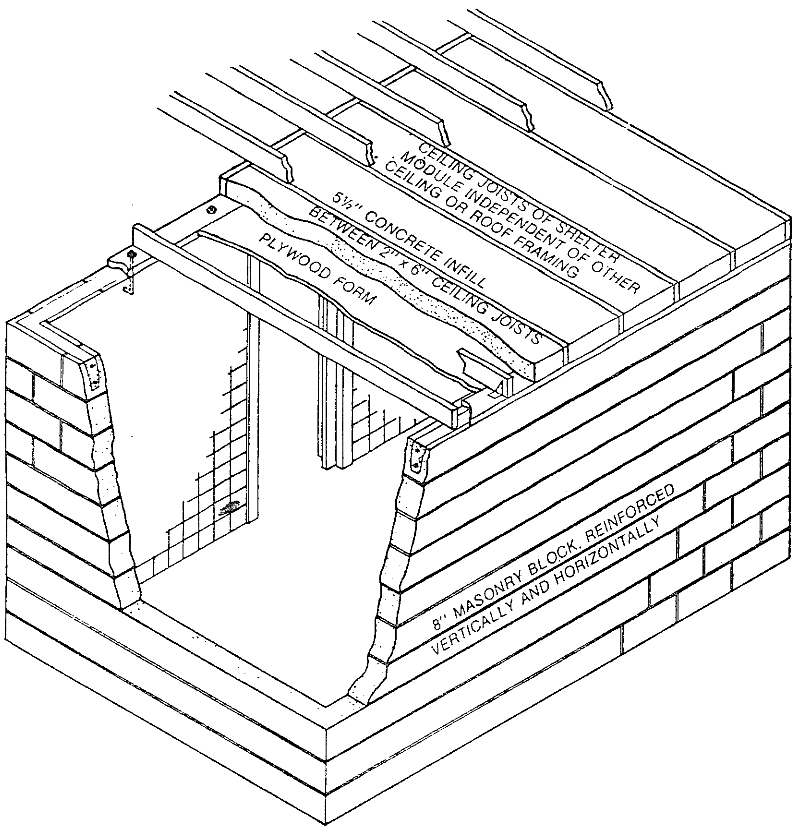
Construction details for this module were developed from investigations of missile penetration in building assemblies, done under the direction of E. W. Kiesling at Texas Tech University. That work has advanced our understanding of protective construction requirements for residences subject to tornadic forces.

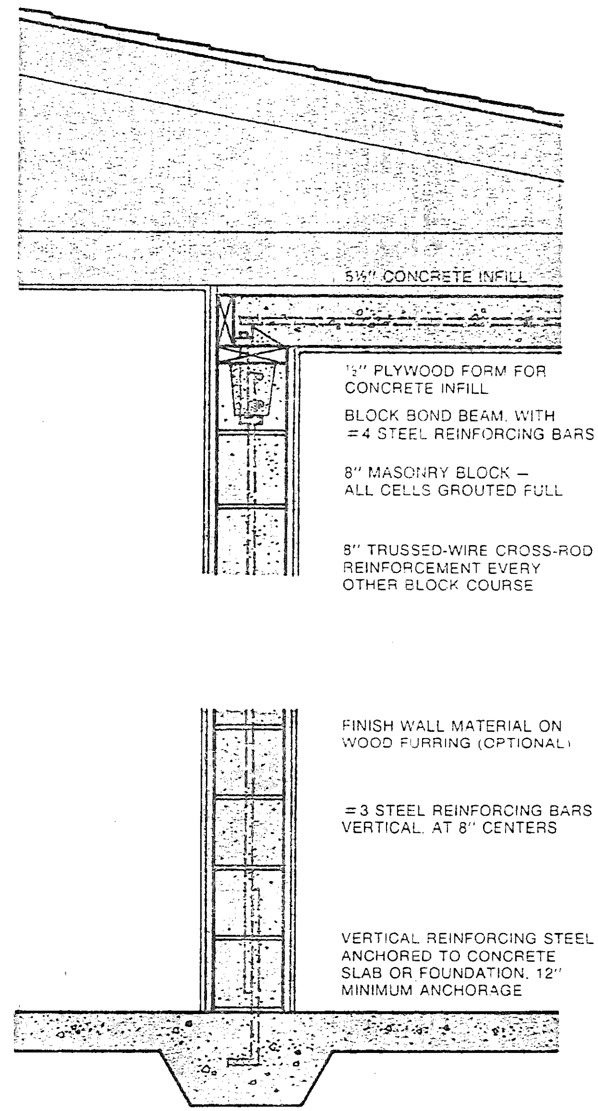
MODULE DESIGN A

MASONRY BLOCK WALLS AND CONCRETE INFILL CEILING

MATERIALS AND ASSEMBLY

- 8" CONCRETE MASONRY BLOCK
- =3 STEEL REINFORCING BARS VERTICAL, AT 8" CENTERS IN BLOCK WALLS, EXTENDED 12" INTO SLAB OR FOUNDATION, AND 12" INTO CEILING INFILL CONCRETE
- TWO =3 STEEL REINFORCING BARS IN EACH SPACE BETWEEN CEILING JOISTS, PLACED PARALLEL WITH JOISTS NEAR BOTTOM OF 5½" CONCRETE INFILL, EXTENDING FULL WIDTH OF SHELTER MODULE
- TWO =4 STEEL REINFORCING BARS CONTINUOUS IN BOND BEAM
- 8" TRUSSED-WIRE CROSS-ROD REINFORCEMENT EVERY OTHER BLOCK COURSE, CONTINUOUS, LAPPED AT CORNERS
- METAL-CLAD DOOR INTO SHELTER MODULE
- TOP PLATE ANCHOR-BOLTED TO BOND BEAM WITH ½" BOLTS AT 2'-0" CENTERS
- 2" x 6" CEILING JOISTS, INDEPENDENT OF (NOT CONNECTED TO) OTHER CEILING CONSTRUCTION, SECURED TO WALL PLATES WITH METAL FRAMING ANCHORS

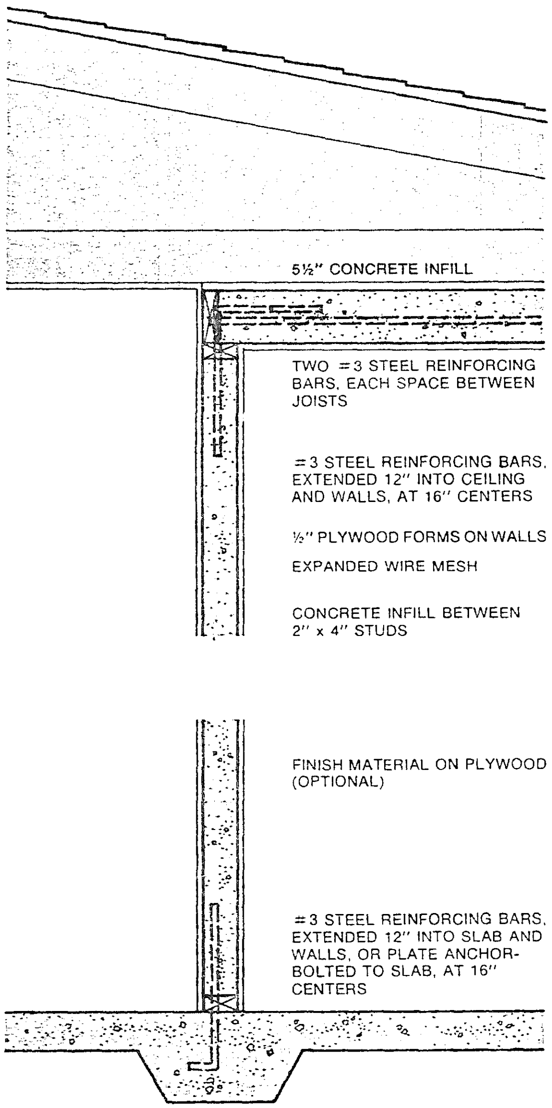




WALL SECTION THROUGH MODULE

MODULE DESIGN B

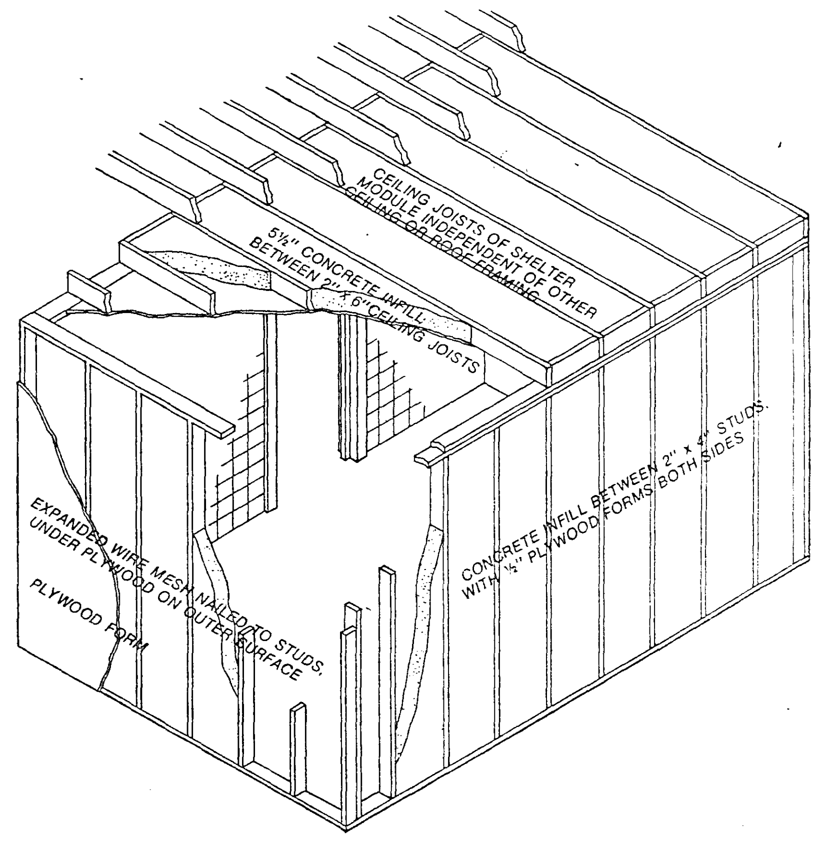
CONCRETE INFILL WALLS WITH PLYWOOD SHEATHING AND CONCRETE INFILL CEILING



WALL SECTION THROUGH MODULE

MATERIALS AND ASSEMBLY

- 2" x 4" STUD WALL, WITH CONCRETE INFILL POURED BETWEEN STUDS, ½" PLYWOOD SHEATHING BOTH SIDES OF STUDS, AND EXPANDED WIRE MESH UNDER PLYWOOD AT OUTER SURFACE
- SHELTER PARTITIONS SECURED TO SLAB WITH ANCHOR BOLTS, OR #3 STEEL REINFORCING BARS EXTENDED 12" INTO WALLS AND SLAB, AT 16" CENTERS
- TWO #3 STEEL REINFORCING BARS IN EACH SPACE BETWEEN CEILING JOISTS, PLACED PARALLEL WITH JOISTS NEAR BOTTOM OF 5½" CONCRETE INFILL, EXTENDING FULL WIDTH OF SHELTER MODULE
- METAL-CLAD DOOR INTO SHELTER MODULE
- TOP PLATE ANCHOR-BOLTED TO CONCRETE INFILL IN WALLS, AT 16" CENTERS
- 2" x 6" CEILING JOISTS, INDEPENDENT OF (NOT CONNECTED TO) OTHER CEILING CONSTRUCTION, SECURED TO WALL PLATES WITH METAL FRAMING ANCHORS



RESIDENTIAL SHELTER MODULE

Estimated cost of construction in the seven county metropolitan area.

Module Design A

Approximate additional cost to include this 7 x 10 x 8 foot high Bathroom/Shelter Module in a new above grade single family dwelling.

Cost Range $ 2100.00 to $ 2600.00

Module Design B

Approximate additional cost to include this 7 x 10 x 8 foot high Bathroom/Shelter Module in a new above grade single family dwelling.

Cost Range $ 1800.00 to $ 2300.00

Estimate provided by:

Company Name: Marv Anderson Homes

Date: 12-3-87

Please return this completed form to:

Building Codes and Standards Division
408 Metro Square Building
Seventh & Robert Streets
St. Paul, MN 55101

RESIDENTIAL SHELTER MODULE

Estimated cost of construction in the seven county metropolitan area.

Module Design A (Block)

Approximate additional cost to include this 7 x 10 x 8 foot high Bathroom/Shelter Module in a new above grade single family dwelling.

Cost Range $ 4,200.00 to $ 4,500.00

Module Design B (Poured Walls)

Approximate additional cost to include this 7 x 10 x 8 foot high Bathroom/Shelter Module in a new above grade single family dwelling.

Cost Range $ 3,500.00 to $ 3,800.00

Estimate provided by:

Company Name: New Horizon Homes, Inc. by Dennis Rambour

Date: 12/9/87

Please return this completed form to:

Building Codes and Standards Division
408 Metro Square Building
Seventh & Robert Streets
St. Paul, MN 55101

SINGLE FAMILY DWELLING SURVEY

City	Total Number Single Dwellings Constructed Jan.-Nov. 1987	Percentage of Total that are are Above-Grade No Basement Dwellings	Percentage of total that are Split-Foyer Partial Basement Dwellings
Alexandria	11	0	0
Bemidji	7	14	0
Blaine	305	3	95
Brooklyn Park	372	0	80
Duluth	64	1	60
Eagan	648	0	60
Mankato	18	0	80
Maple Grove	473	0	70
Marshall	21	0	9.5
Rochester	325	1	30
Worthington	9	0	0
Total Number of Dwellings	2253 Dwellings	14 Dwellings	2239 Dwellings

5. SUMMARY.

a. The residential shelter modual concept is the least expensive method of providing shelter in above grade single family housing not considering manufactured (mobile) homes.

Manufactured (mobile) homes are constructed in conformance with the Federal Manufactured Home Construction and Safety Standards. This is a federal preemptive code which cannot be altered by the states. There would be no practical way of providing shelter within a manufactured (mobile) homes since in most instances they are not placed on permanent foundations. A shelter outside of the structure would be more practicle for this type of housing.

Although the study was to be directed at "above grade" housing, another type of housing can be included. Split foyer homes are very popular, based on the survey on Page 12. The split foyer home, as it is commonly called, has the lower level only 3 to 4 feet below grade and does not afford the protection of a full depth basement.

* b. Over a 33 year period (1953-1986) an average of 2 people have been killed by tornadoes each year in Minnesota. During the period from 1981 to 1986 only one death was attributed to tornadoes in Minnesota. Injuries over the same 33 year period averaged about 4 per year except for the Roseville tornado in 1981 when 94 injuries were reported. Based on these figures, risk to life and limb could be considered minimal.

c. The estimates received from several home building contractors places the cost of a shelter module in a new home from $1800.00 to $4500.00, added to the cost of the home.

d. The question of whether the cost to provide adequate protection by requiring emergency storm shelters in all new construction is justified in light of the statistical minimal risk due to extreme winds and tornadoes is a public policy issue for legislative consideration.

* Information obtained from the Minnesota Department of Public Safety, Emergency Services Division as taken from a publication by the National Weather Bureau titled "Storm Data".