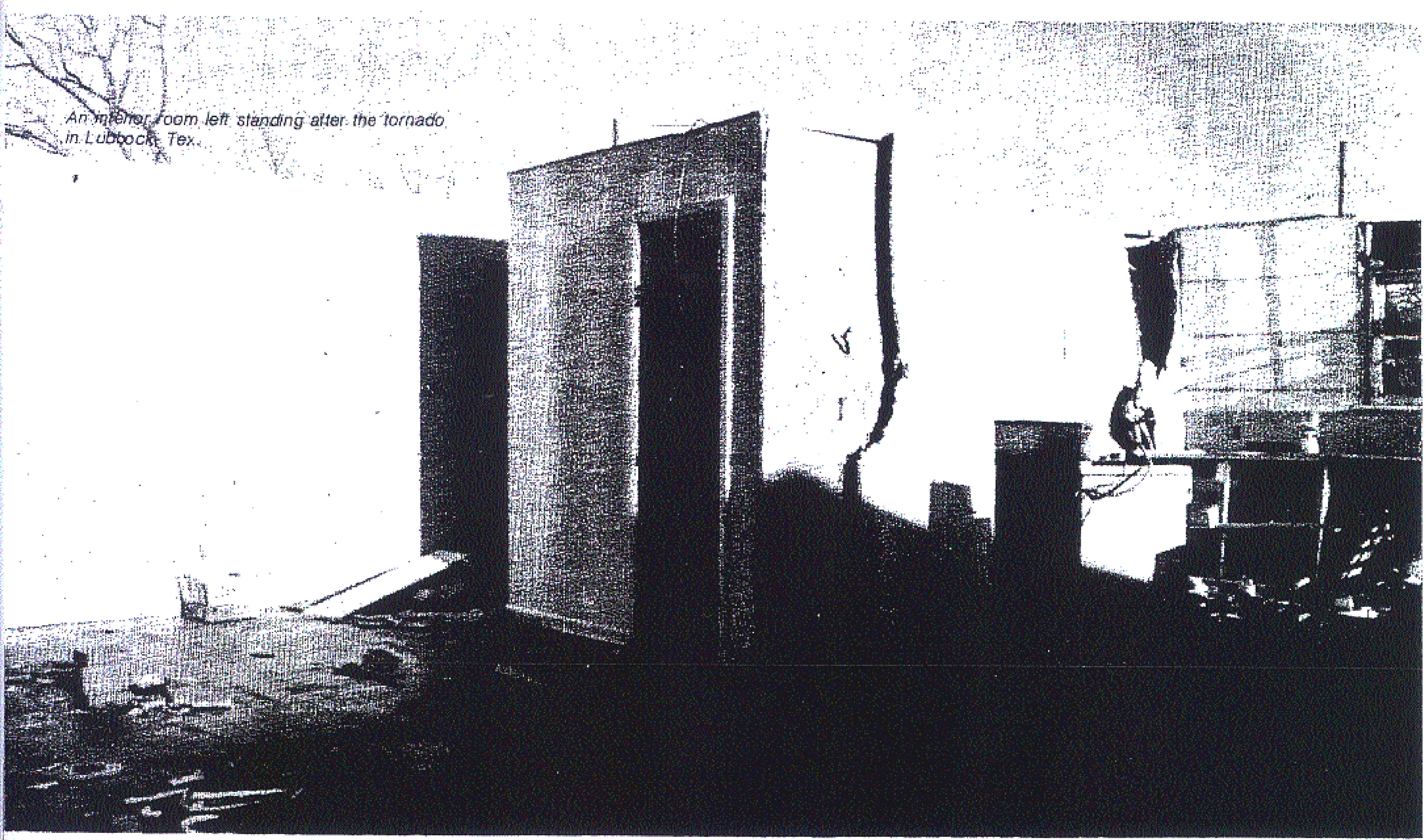

An interior room left standing after the tornado in Lubbock, Tex.

In-home shelters from extreme winds

Texas Tech had $135 million of tornado-damaged structures as a lab for studying resistance to extreme winds. One idea that emerged is the inresidence shelter, economical and easily accessible. Tests were devised to see if such a structure could be made impenetrable by flying debris, the greatest cause of death during tornadoes. Some units have been built and the idea is easily applicable to the large numbers of existing homes in tornado areas that have no basements.

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INRESIDENCE SHELTERS promise protection against severe winds that, among violent natural disasters, cause damage second only to floods. Destruction caused by earthquakes is a considerably distant third. More than three billion man-hours are spent annually in the United States under tornado watches. Tornadoes cause more than $75 million in property damage and kill more than 125 people in the U.S. each year. The toll this year is far above average.

Above-ground safety

Until recently most people thought that the forces of a tornado were so awesome that nothing could be done to provide safety above ground economically. Basements, cellars and some community shelters can be found but not in numbers or locations to offer protection to most people.

Because of the cost of making the entire structure safe against extreme winds, the concept of a protective module within the home was introduced. A small interior room such as a closet or bathroom, readily accessible from all parts of the house, can be the storm shelter. The idea is applicable to both existing residences and newly constructed ones. All parts of the module—walls, ceilings, doors and openings—must be properly designed to provide occupants protection even if the surrounding structure is severely damaged or destroyed.

Background

The Lubbock tornado of May 11, 1970 provided civil engineers of Texas Tech a $135 million laboratory in the form of damaged structures. In Lubbock and in the dozens of tornado damaged cities studied since the Lubbock storm, researchers found portions of many structures still standing, even in the hardest hit areas. Often a small room, such as a closet, bathroom, or

Fig. 1 One of the wall constructions being tested at Texas Tech for impenetrability and for possible use in inresidence shelters. The vertical wood studs are faced with ¾ in. plywood and filled with lightweight concrete reinforced with steel mesh.

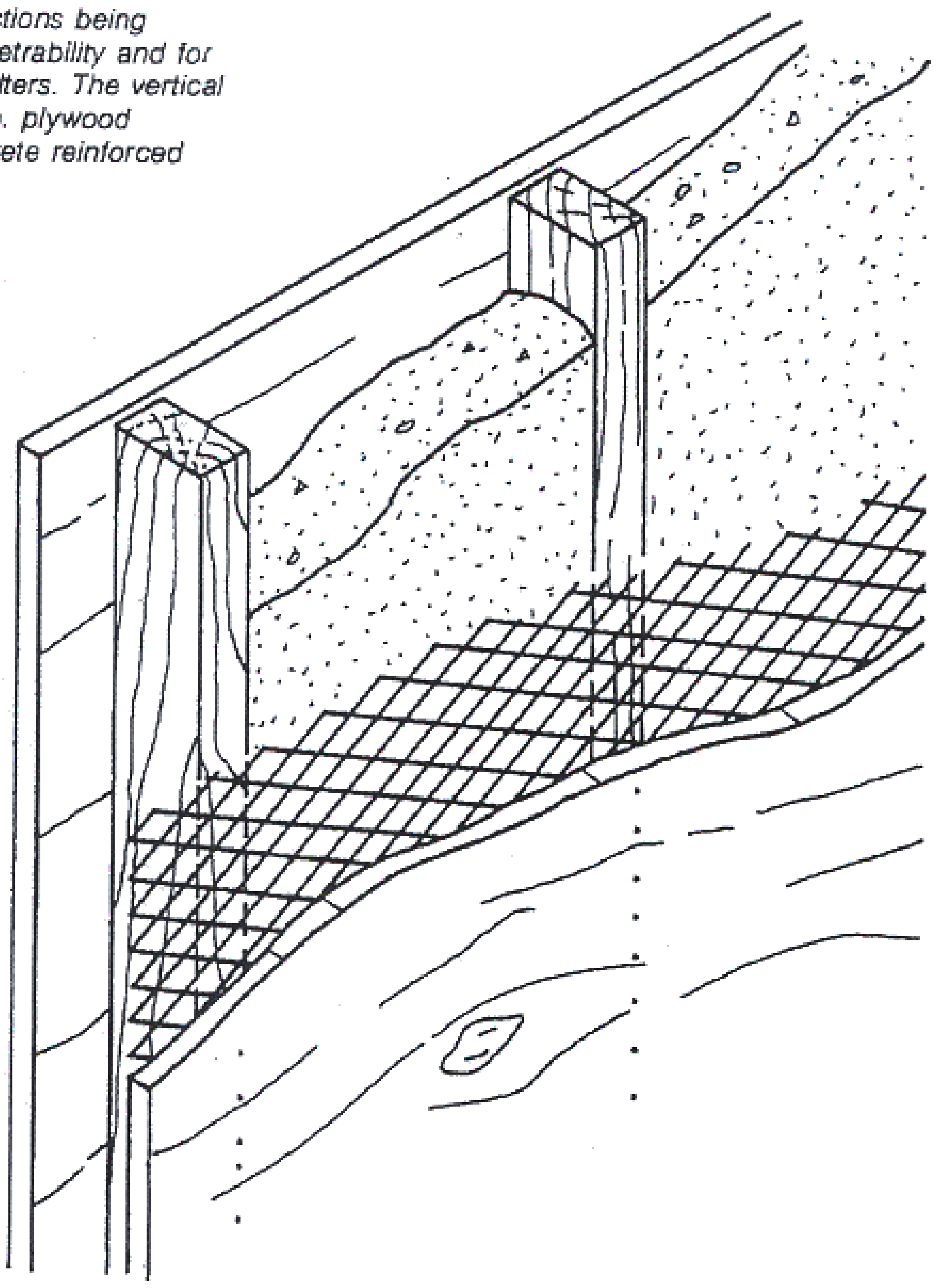

Table I
RESULTS OF VARIOUS 2 x 4 TIMBER TESTS AT 65 MILES PER HOUR

Panel Construction	Impact Energy (ft-lb)	Description of Behavior
¾ in plywood	481	Missile passed through
Expanded metal (¼ in) over ¾ in plywood	1411	Missile passed through
¾ in plywood over expanded metal	2650	Plywood was penetrated, several wires broken
¾ in plywood—lightweight concrete—¾ in plywood panel	2650	Plywood was penetrated, concrete broke in cone shaped hole, bottom plywood cracked
¾ in plywood-expanded metal-lightweight concrete-¾ in plywood panel	5645	Plywood was penetrated, several wires broken, concrete broke in cone shaped hole, bottom plywood had 1-in deep bulge
¾ in plywood-lightweight concrete-expanded metal-¾ in plywood panel	5645	Plywood was penetrated, concrete broke in cone shaped hole, 3-in deep bulge in wire, plywood cracked
Solid (filled) door	2650	Missile passed through
16 gage steel over hollow-core door	2650	Metal deformed, door destroyed
Expanded metal over filled door	2258	Missile passed through
Filled door over expanded metal	2258	Missile passed through door, large deformations in wire
Hollow-core door over 16-gage steel	2258	Door destroyed, large deformations in metal
1¾ in solid wood	2258	Wall section destroyed
14 gage steel over 1½ in solid wood door	5362	Large deflection of metal, door cracked
Concrete block beam filled with lightweight concrete	2822	Block beam destroyed
Concrete block beam filled with lightweight concrete with #3 steel bars in each cavity	5645	No penetration or cracks
Preformed, steel reinforced masonry wall panel, about 4 inches thick	5645	No penetration; one horizontal mortar joint cracked, allowing about 1 in lateral deformation in 4 ft span, impacted brick did not crack; missile shattered

interior hallway offered some protection to occupants. The concept of the inresidence shelter naturally followed.

Advantages

The accessibility of an inresidence shelter near the center of the house at the "living level" makes it highly advantageous over a cellar or community shelter. There is extreme danger of being struck by flying debris in trying to reach a shelter outside the house. The inresidence shelter idea permits a family to continue regular living patterns during a weather watch knowing that a safe place is only a few seconds away.

Basements offer adequate shelter from storms and are readily accessible but their high cost prevents widespread use. Also, the inresidence shelter can be economically constructed within an existing house—a basement cannot.

Design

Structural integrity of the shelter is the primary design consideration. In a storm, it must be able to withstand the direct forces of the wind and secondary forces such as those imposed by the collapse of the house onto the shelter. Direct forces from winds can be estimated with reasonable confidence—loads up to 140 psf (683 kg/m^2) are possible on some surfaces. Secondary loads are more difficult to predict and are likely to be more localized than direct windloads. Venting can be provided to relieve pressure differentials.

Of prime importance to structural integrity are adequate fasteners. The ceiling must be securely connected to the walls, the walls to each other, and to the floor or foundation. This can be done by bolting units to the floor slab, drilling into existing slabs, or by using vertical reinforcing bars to lock floor, walls and ceiling together.

Large factors of safety for collapse from windloads can be used without seriously affecting costs. A small room properly fastened and designed to resist penetration by missiles inherently possesses great structural integrity.

Walls, doors, and ceilings of the shelter must also be able to prevent penetration. The mechanics of penetration are not well understood in the case of a windborne missile impacting a wall section built of typical construction materials. Intuitively, the energy at impact would seem to be an important measure of the missiles ability to penetrate, while mass, shear strength and ductility of a shield (wall, ceiling, or door) would seem important in resisting penetration by a missile. More study and data are needed before analytical techniques can be established to predict performance.

At Texas Tech, a design missile was chosen for research, a 12 ft (3.7 m) 2 x 4 board weighing approximately 17 lbs (7.7 kg), striking on end, at 100 mph (161 km/hr).

Test program

Determining the ability of a wall section to prevent penetration by a missile was considered the most basic and urgent research need in attempting to design an inresidence shelter. Shortage of funding precluded construction of a sophisticated missile launching facility. A very inexpensive, simple-to-operate drop test facility was devised to guide a missile in free-falling flight from a height of 155 ft (47.2 m). Since the desired speed of 100 mph cannot be reached with this facility, the mass of the missile is increased to produce an energy at impact equivalent to that of a 17 lb missile traveling at that speed. Tests are performed with a modified 2 x 4 weighing approximately 40 lbs (18.2 kg) striking at speeds up to 63 mph (101 km/hr).

The wall section being tested is usually supported on two edges by a wooden box partially filled with sand to arrest a missile that breaks through.

Either penetration or excessive deformation constitutes failure of the wall section. To date, about 20 wall sections employing various combinations of materials and fabrication methods have been tested. Table I shows some of the results. Three have performed successfully, others show promise.

Cost

Since the cost of the inresidence shelter must be competitive with other shelters such as cellars and basements, it must be constructed with available, inexpensive materials that can be handled by "ordinary" building crews. For a small room, say 8 x 8 ft (2.4 x 2.4 m) occupant protection can surely be provided for less than $1000 if the shelter is built at the same time as the house (see box). As designs are optimized and construction experience is acquired, this cost *should* diminish.

In houses already built, the cost will naturally be somewhat greater.

Workable concepts

Research at Texas Tech has produced at least three concepts that meet criteria for structural integrity, missile protection and low cost. One idea, shown in Fig. 1, is expanded metal and lightweight concrete between sheathing of ¾ in. (19 mm) plywood. Another consists of concrete blocks filled with light-weight concrete and reinforced with steel bars. A third concept showing great promise is a pre-cast, reinforced masonry panel approximately four in. (102 mm) thick; designed as a load-bearing wall for residential construction and easily reinforced for greater missile protection.

The most economical design with present knowledge might be a combination of the filled, reinforced concrete blocks serving as walls, securely attached to a cast-in-place concrete ceiling. All of the necessary materials are commonly used and fabrication requires no new technology.

Openings such as doors can be economically closed with a combination of swinging and sliding doors. An attractive swinging door can be provided for normal use; a composite plywood and steel sliding door can be provided for the occasions when the room is used as a storm shelter.

Future possibilities

In the future, factory built bathrooms with plumbing, wiring, and fixtures already installed and with walls capable of repelling a missile might possibly be produced and made available as off-the-shelf items. The advantages of the inresidence shelter might then be combined with the advantages of mass production to produce bathrooms offering protection at little or no additional cost over conventional construction.

At present, an inresidence shelter can offer at very little cost, protection from tornadoes and, only slightly less important, freedom from the anxiety caused by a severe weather watch. ▽

Ernst W. Kiesling is Chairman of the Civil Engineering Dept. at Texas Tech where an extensive research program is underway to mitigate the effects of disaster.

David E. Goolsby has been active in the design against missile penetration of the inresident shelter components.

Tornado-proof closet a fraction of cost of basement

The closet will undoubtedly be the most popular room in the Horace Mitchell home next time a tornado watch is on in Lubbock, Tex., scene of a disastrous tornado in 1970. Owner Mitchell, a local attorney, says the windproof shelter cost him about $600 and estimates that a basement in his new home would have cost $3-4 thousand.

Mitchell was having his house built when local newspapers carried stories of author Kiesling's research at Texas Tech on windproof shelters. He asked Dr. Kiesling to work along with his architect to plan such a shelter in the new house. Construction had already begun and studs were up, somewhat limiting possible approaches. An interior walk-in closet was chosen and vertical steel reinforcing bars longer than the side walls were cast into the floor slab around the closet perimeter. After this cage-like effect was achieved, ¾ in. plywood was nailed to the studs and used as forming for four ft (1.2 m) of conventional concrete in the walls around the bars.

The four ft (1.2 m) of concrete was considered adequate since occupants could sit down during a tornado. Dr. Kiesling points out that the heavy concrete above this height could create serious forming problems, requiring extra support, and thus extra expense. In the accompanying article, he discusses the use of lightweight concrete, augmented by steel mesh for entire wall height in such shelters.

Ordinary closet

Next, the ceiling joists in the closet area were disconnected, insuring the structural independence of the unit. The steel reinforcing bars extending above wall height were bent and joined to the ceiling, thus fastening the entire unit to the floor. An extra-thick door, faced with the ¾ in. plywood, a reinforced latch and a vent complete the protective closet. The interior was finished to make it indistinguishable from any other closet in his home, says owner Mitchell.

Dr. Kiesling thinks the $600 price tag would have been even lower if the room could have been planned before construction on Mitchell's home began. He intends to prove it this fall with a demonstration house he will build and occupy himself. The house, which will feature energy conservation too, will be a workshop for construction techniques on the inresidence shelters. V.F.