Nov. 3, 1964 P. GRAHAM 3,154,888

BUILDING CONSTRUCTION

Filed March 23, 1960 5 Sheets-Sheet 1

FIG. 1

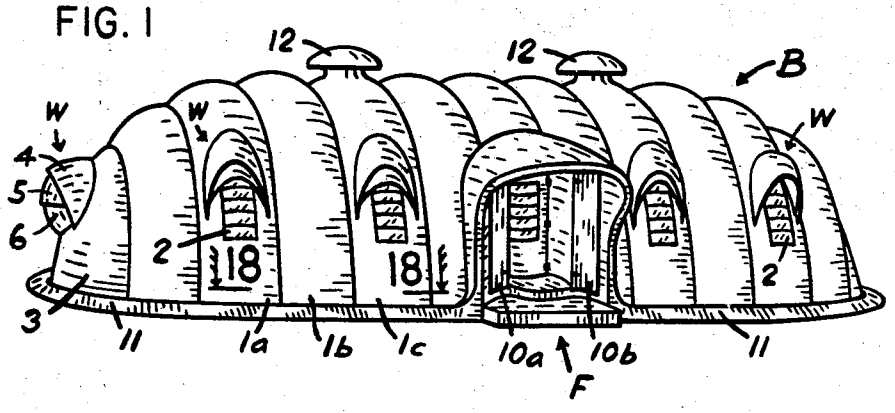


FIG. 2

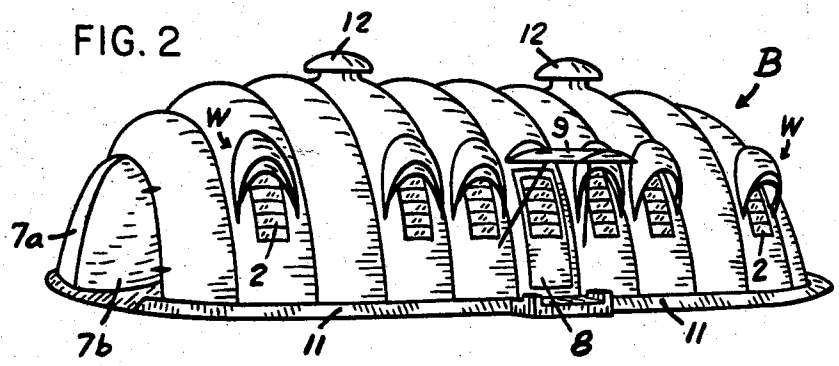


FIG. 3

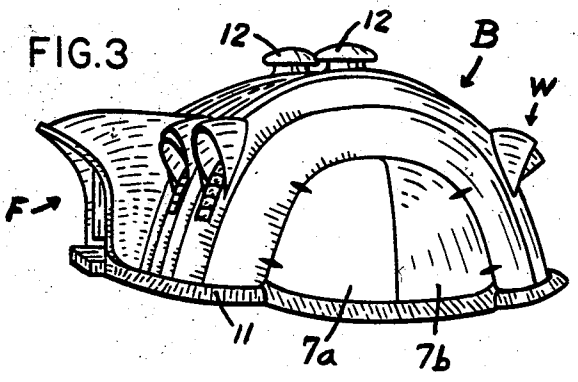
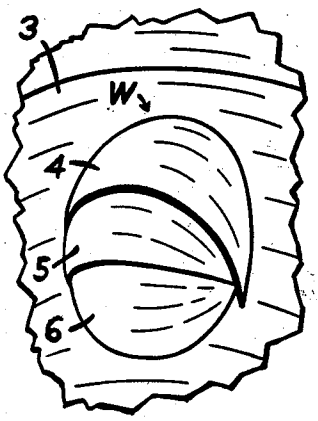


FIG. 4



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BUILDING CONSTRUCTION

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FIG. 5

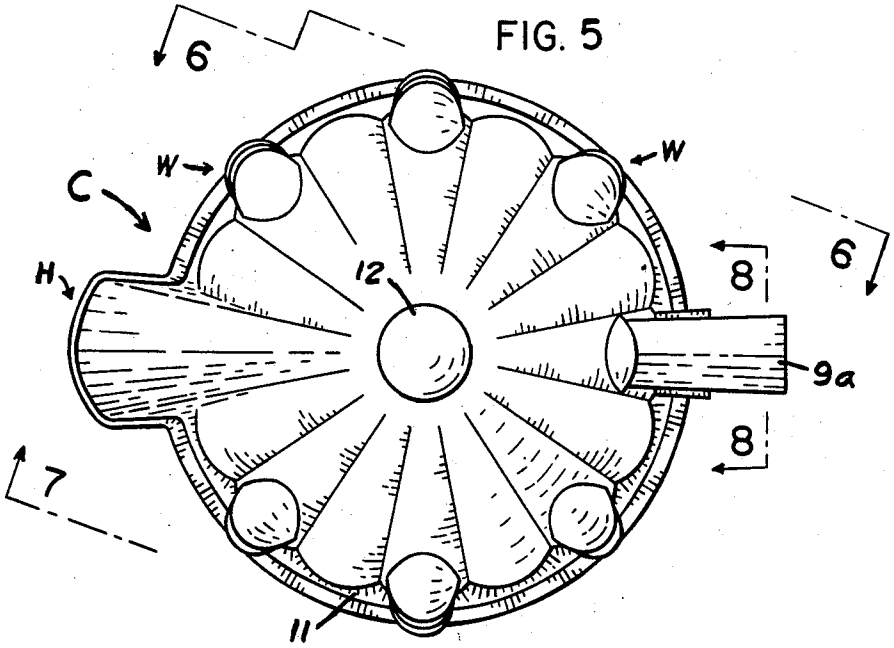


FIG. 6

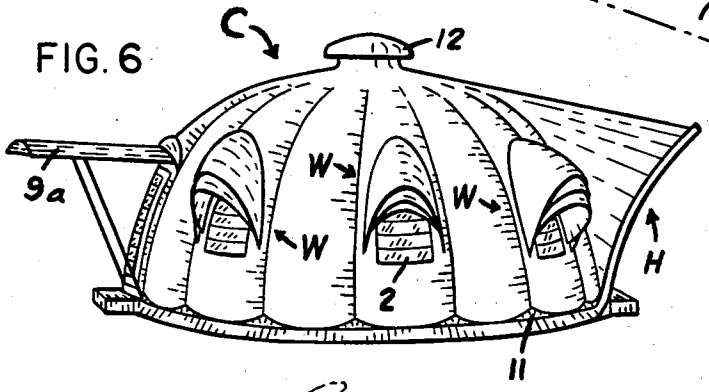


FIG. 8

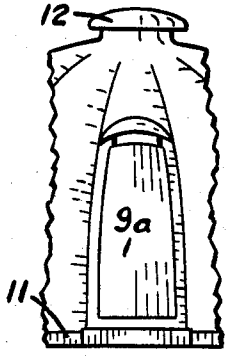
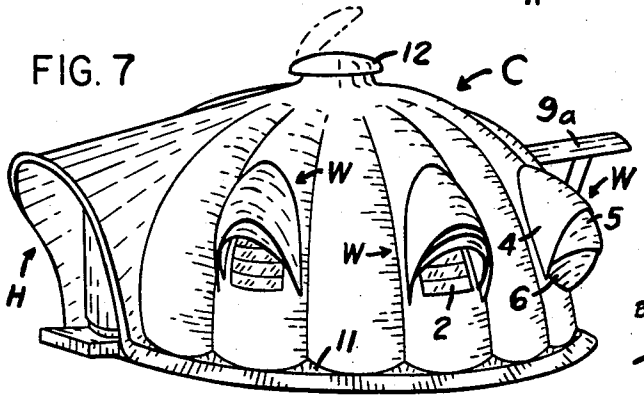


FIG. 7



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BUILDING CONSTRUCTION

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FIG. 9

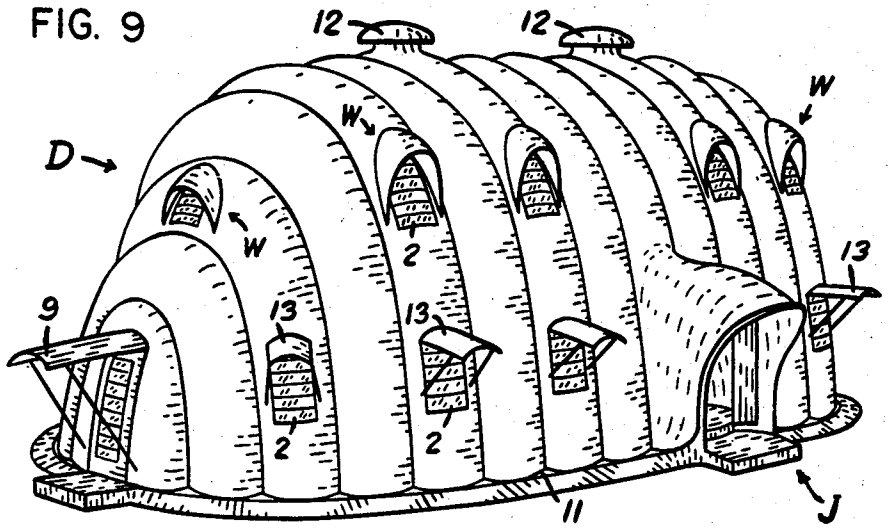


FIG. 10

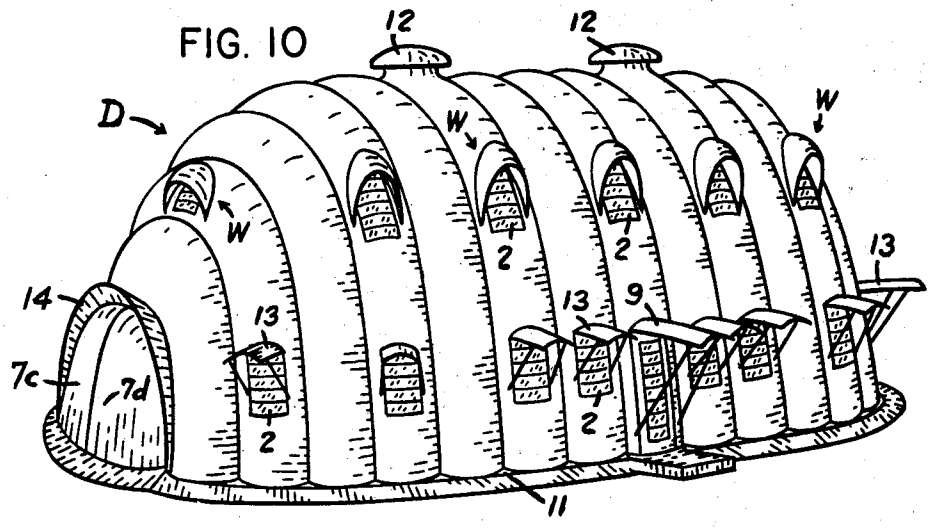


FIG. 11

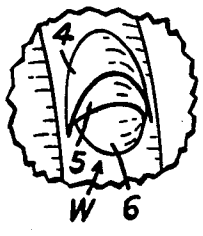


FIG. 12

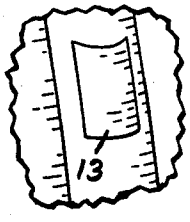
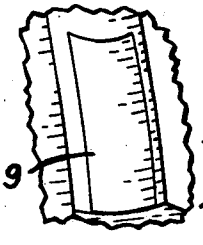


FIG. 13

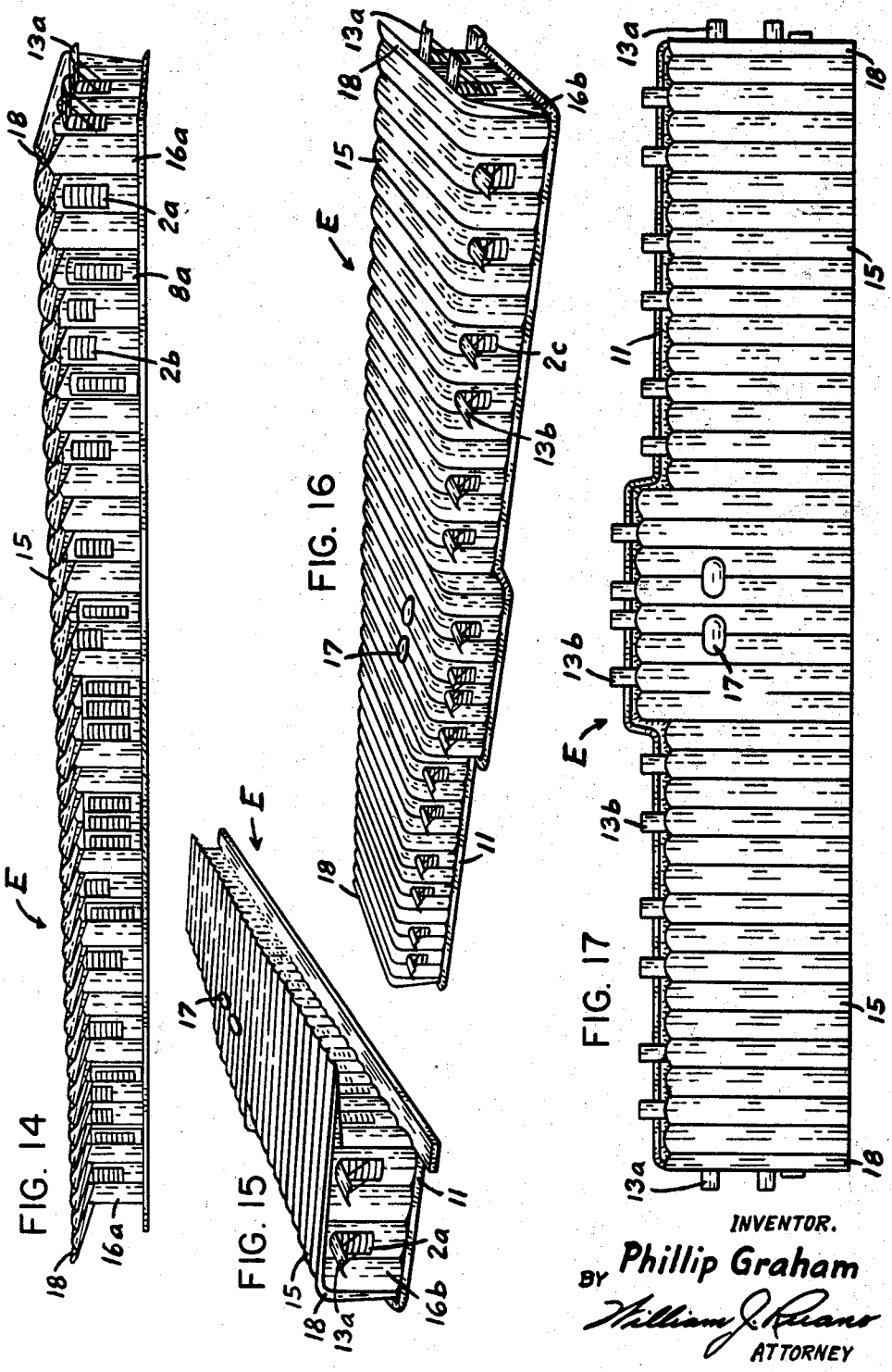


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BUILDING CONSTRUCTION

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BUILDING CONSTRUCTION

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FIG. 18

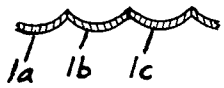


FIG. 19

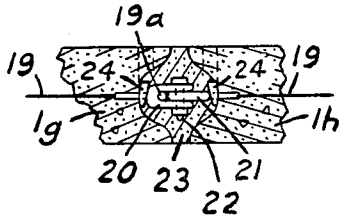


FIG. 20

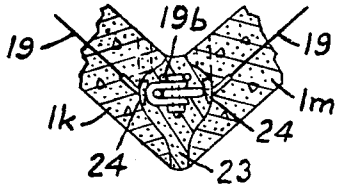


FIG. 21

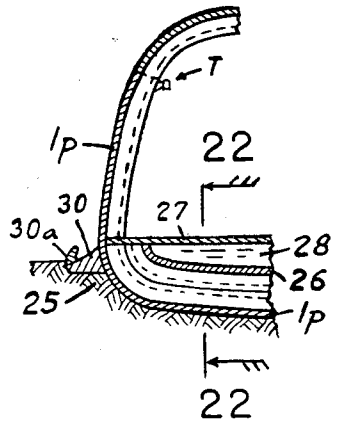


FIG. 22

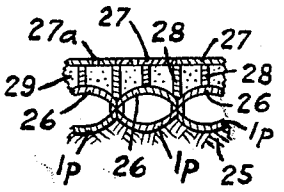


FIG. 23

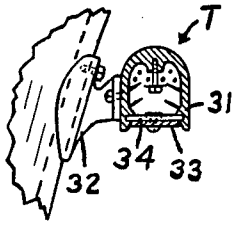


FIG. 24

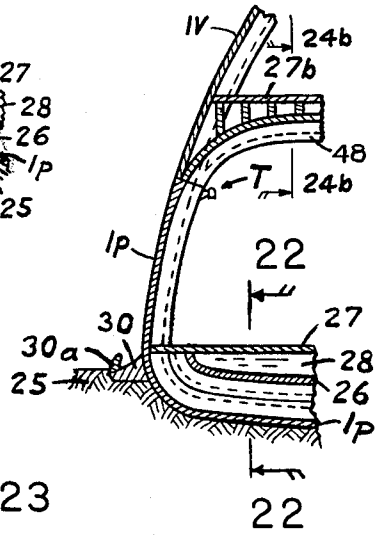


FIG. 24a

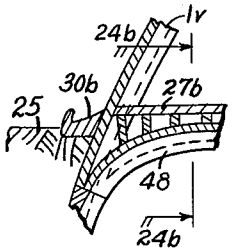


FIG. 25

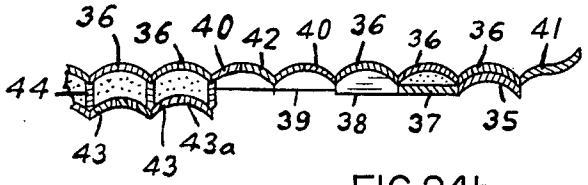


FIG. 24b

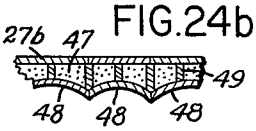
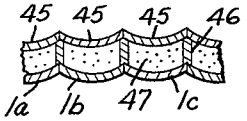


FIG. 18a



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United States Patent Office 3,154,888 Patented Nov. 3, 1964

3,154,888

BUILDING CONSTRUCTION

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Filed Mar. 23, 1960, Ser. No. 17,167
12 Claims. (Cl. 50—52)

This invention relates to building construction including curved, thin-shell, reinforced, buildings of cementitious materials and plastics which can be readily constructed with curved precast panel sections, which sections can be interlocked or bonded together to obtain an integral building shell of great strength, and relates also to the methods and apparatus for constructing the buildings. This invention is a continuation-in-part of my co-pending applications Serial No. 456,684, filed Sept. 17, 1954, entitled Flexible Building Panel Form, now abandoned and Serial No. 785,273, filed Jan. 6, 1959, now Patent No. 2,971,237, entitled Flexible Building Panel Form. Both application Serial No. 456,684 and application Serial No. 785,273 are each in turn a continuation-in-part of application Serial No. 259,354, filed December 1, 1951, now Patent No. 2,897,668, entitled Building Construction.

This invention particularly refers to thin-shell houses and other buildings of cementitious materials and plastics having rib-like corrugations that are similar to ribbing on a sea shell of the scallop type. The buildings may be constructed speedily at low cost with precast reinforced concrete panels, unskilled labor being usable to make and erect the panels. The buildings are pleasingly attractive in appearance, strong and durable as are ribbed sea shells. The buildings would have far greater strength and durability than other types of buildings using equal amounts of material, so as to provide security for the occupants or users of such building against the terrifically violent forces of nuclear blasts (in fringe areas), as well as less violent forces such as those from shock waves from aircraft flying at supersonic speeds, hurricane-like winds, explosions, tidal and fresh water floods, avalanches, earthquakes, and fires. Furthermore, the buildings may have self-sealing shutters and/or self-sealing doors and windows which would keep out deadly bacteria and poisonous gas dropped from enemy guided missiles. In addition, the sealing along with the thin building shell allows covering such buildings with soil in critical bomb target areas in war-like times, to form a shield against the heat and deadly gamma rays emitted by atomic blasts, also to camouflage the building. The invention contemplates encasing existing buildings with the thin-shell buildings to protect the existing buildings from nuclear blasts and other violent forces.

In areas where sub-surface water makes underground shelters impractical, the thin-shell building may have a double shell with soil between the shells to act as an insulator against nuclear fallout and the like.

Most present day houses lack the means to provide adequate shelter from the hazards that exist today, therefore the houses do not fulfill their basic purpose, since primarily a house is supposed to be a shelter to protect the occupants.

Most of the present day building designs, building products, and methods of construction for building houses and other small buildings cannot be used to construct pleasingly attractive buildings of great strength and great durability at an economically sound cost since they ineffectively use materials and labor. Furthermore, in a war-like emergency period, when vast numbers of strong durable buildings would have to be speedily built to furnish protection to the great mass of the people, present day building means would be too slow and would require too much material to meet the demand. It is unlikely

that wood will be available in the future for large scale housing construction. The output of wood for construction work is lessening while the cost is increasing, due to the great increase in the use of wood for making synthetic fibers, plastics and paper.

In general, present day building means in the field of small buildings are inadequate for future housing needs. Present day types of houses are extremely weak against side pressures, therefore they would offer little protection from the violent blast pressure of an H-bomb (in fringe areas). Furthermore, present day houses offer little resistance to fire such as that from war time incendiaries.

In general, in suburban areas, there is need for dual purpose small buildings that can be used for normal living and act as shelters from warfare. There is urgent and widespread need for low cost blast resistant buildings for use in possible nuclear blast fringe areas around industrial and military centers, since such centers would be prime targets for guided missiles with nuclear warheads. Such buildings also need to be seal-tight to prevent entry of deadly bacteria, deadly gases, and incendiary particles. There is need everywhere for buildings with dense concrete shells that are smooth, free of cracks, and sloped for good drainage, so that nuclear fallout can be easily flushed off with a spray and the concrete can reduce the hazard from the rays of the fallout.

There is also need for farm buildings that offer protection to people, livestock, and crops from the aforementioned wartime hazards.

There is need for dual purpose vacation-refuge houses that are pleasingly attractive, durable and low in cost. Such houses in remote non-strategic areas could act as vacation homes and as refuge shelters in wartime if the occupants had to evacuate their homes in critical target areas. The vacation-refuge houses need to be resistant to fallout, forest and brush fires, also resistant to damage by vandals.

There is urgent need for low cost attractive fire-resistant, durable houses for families with low income, particularly for the aged, weak, and crippled who have small social security pensions and the like. People with such low fixed incomes cannot pay for present day modern housing due to monetary inflation. Such low income housing is much needed in the southern part of the country where adequate housing must furnish protection from hurricane winds, torrential rains, and destructive insects. In addition, the housing for low income families should have characteristics that would require little expenditure for maintenance, and the minimum expenditures for heating, venting and air-conditioning.

There is need for cementitious buildings and the like that are durable and which cannot be burned or be torn down and stolen for gain by vanadals or possible invading armies, thus being unlike metal buildings which have high scrap value.

The present application pertains to means to provide the needed buildings recited above, particularly for construction during warlike times since the buildings embodying the present invention require very little metal or other materials that are highly strategic materials during such times.

The present application describes improved means to build stronger and more useful blast resistant buildings than were described in my co-pending applications Serial No. 456,684, and Serial No. 785,273.

An object of my invention is to provide a low cost, pleasingly attractive thin-shell building having a shell of thin self-supporting rib-like panels bowed outwardly in width, the panel edges being in edge to edge relationship to form a ribbed surface like the outer surface of a scallop shell, the building being durable, fire-resistant, non-cor-

rosive, strong, able to resist violent nuclear blast forces and which will resist deterioration from exposure to the elements.

Another object is to provide a thin-shell concrete building with a ribbed surface similar to that of a scallop shell, the building shell being constructed of thin, bowed, reinforced, precast concrete panels whose edges are interlocked with pins and key-bonded with concrete to obtain continuity in the structure so the panels co-act to provide great strength to the building, the building being erectable dry during inclement weather by pin connecting the panels, the grout being inserted at a later suitable period.

A still further object is to provide a ribbed thin-shell concrete building with panels that form the ribs, the building having bowed closures to maintain continuity to the building.

A still further object is to provide a ribbed thin-shell building that can be used for normal living purposes and be covered with soil and be used as a strong bomb shelter during wartimes.

Other objects of my invention will become more apparent from the following description taken with the accompanying drawings wherein:

FIG. 1 is a front perspective view of a thin corrugated shelled building embodying my invention;

FIG. 2 is a rear perspective view of the building shown in FIG. 1;

FIG. 3 is an end perspective view taken from the right of FIG. 1;

FIG. 4 is an enlarged, fragmentary, perspective view taken from the left of FIG. 1;

FIG. 5 is a plan view of a dome shaped building which has a thin corrugated shell;

FIG. 6 is a perspective, elevational view taken along line 6—6 of FIG. 5;

FIG. 7 is a perspective, elevational view taken along line 7—7 of FIG. 5;

FIG. 8 is a fragmentary, elevational view showing a retractable door-canopy in a lowered position to allow it to act as a storm door;

FIG. 9 is a front, perspective view of a two story building which has a thin corrugated shell;

FIG. 10 is a rear, perspective view of the building shown in FIG. 9;

FIG. 11 is a fragmentary, perspective, elevational view showing a typical dormer with closed shutters;

FIG. 12 is a fragmentary, perspective, elevational view showing a typical canopy-shutter in a closed position;

FIG. 13 is a fragmentary, perspective, elevational view showing the canopy for the rear door in a lowered position to allow it to act as a storm shutter;

FIG. 14 is a perspective view showing principally the front of a rectangular building which has a thin corrugated shell;

FIG. 15 is a perspective view showing principally an end of the building shown in FIG. 14;

FIG. 16 is a perspective view showing principally the rear of the building shown in FIG. 14;

FIG. 17 is a plan view of the building shown in FIG. 14;

FIG. 18 is a fragmentary, sectional view taken along line 18—18 of FIG. 1;

FIG. 18*a* is a fragmentary, sectional view similar to FIG. 18, but showing a typical double shell.

FIG. 19 is an enlarged, fragmentary, sectional view, showing a typical joint between the ends of two curved precast panels having reinforcing;

FIG. 20 is an enlarged, fragmentary, sectional view, showing a typical joint between the side edges of the two bowed in width precast panels having reinforcing;

FIG. 21 is a fragmentary, sectional view taken through a one story arched structure having a thin corrugated shell like those of the buildings shown in FIGS. 1 and 5;

FIG. 22 is a fragmentary, sectional view taken along line 22—22 of FIG. 21 and FIG. 24;

FIG. 23 is an enlarged, fragmentary, sectioanl elevation showing a conduit means positioned as shown in FIGS. 21 and 24;

FIG. 24 is a fragmentary, sectional elevation taken through a two story arched building having a thin corrugated shell;

FIG. 24*a* is a fragmentary, sectional view that is similar to FIG. 24, it differs by having the ground line adjacent to the second floor level.

FIG. 24*b* is a fragmentary sectional elevation, taken along line 24*b*—24*b* *of* FIG. 24 and FIG. 24*a*.

FIG. 25 is a fragmentary, sectional view showing some typical panel combinations for buildings having curved thin shell construction.

FIGS. 1 to 17 inclusive show exterior views of various types of strong, durable, low cost buildings which have thin shells that are corrugated, the corrugations having an appearance like that of ribs on the ribbed surface of a scallop type sea shell.

The shells of the buildings may be made of cementitious materials or plastics. Wire may be used to reinforce cementitious shells, and fiber glass may be used to reinforce plastic shells. Fiber glass may also be used for reinforcing the cementitious shells.

The scallop shell motif of the buildings may be maintained at the closures by having outwardly bowed windows, doors, shutters and dormers. I have provided such suitable closures, since my Patent No. 2,877,517 describes low cost, thin, strong, curved jalousie type windows that are cushionable, blast resistant, self-sealing and frameless. My patents, No. 2,770,850, No. 2,826,787, and No. 2,826,788 describe low cost, thin, strong, bowed doors and shutters that are blast resistant, self-sealing and frameless.

FIGS. 1 to 4 inclusive show exterior views of an arched, elongated building B. FIGS. 5 to 8 inclusive show exterior views of a dome-like building C. FIGS. 9 to 13 inclusive show exterior views of a two story, arched, elongated building D. FIGS. 14 to 17 inclusive show exterior views of a rectangular shaped building E. These building shells may be made of concrete, plastic and the like. These buildings may be readily constructed by cast-in-place methods, such as by the method of using inflated balloon forms and spraying the shell material onto the forms. The balloon forming system is low in cost for thin shell construction when the shell has little reinforcing, but it is a very costly construction means when reinforcing is stretched over the form.

Buildings B, C, D, E, and the like, may be built at low cost with panel means described in my co-pending application, Serial No. 785,273, now Patent No. 2,971,237, along with means described in my Patents No. 2,897,668 and No. 2,920,475. Patent No. 2,897,668 describe most of the corrugated panel construction means. The co-pending application mainly describes flexible elastic form means for molding the panels, in addition it describes some means to make improved panel construction.

Buildings B, C, D, E, and the like, may have thin reinforced concrete shells, which type of construction allows highly efficient use of material and labor. The shapes of these building shells deflect, absorb and resist loads more effectively than do conventional types of building shells having flat surfaces or slightly curved surfaces. The thin curved panels of the buildings have curved shapes that make them strongly resistant to loads that tend to bend or buckle them, thereby allowing shell portions with a small amount of reinforcing wire to support their own weight and a live load over long spans. The panels may have prestressed reinforcing strands, particularly the longitudinal strands, to obtain stronger panels without increasing the amount of material in the panels. Since the thin curved reinforced panels are very strong for their weights, the weights of the buildings are low compared to those for conventional masonry buildings, thus allowing smaller, less costly foundations.

The useful characteristics of concrete are exploited in the buildings while the objectionable characteristics have been curtailed or have been given little opportunity to act. Extensive use is made of arch construction to utilize the concrete to best advantage, that is, in compression. The shells would not have objectionable cracks because the arches that form the corrugations and arches spanning the buildings can bulge outwardly due to expansion caused by heat, and they can flatten to an extent due to contraction caused by cold weather. The compressive force of the bowed shapes keep cracks squeezed tightly closed, thereby resisting water penetration. The arched spans of thin corrugated panels do not have to depend to a large extent on reinforcing steel, and the arches are not likely to collapse if fire should penetrate the concrete for a short period and weaken the reinforcing. A large amount of vermiculite may be used in the shell aggregate to slow the passage of heat from fires and the sun. When arched shelters, like buildings B, C, and D are to be built in trenches and are to be covered with soil, the shell may be built without reinforcing since the soil will restrain the arches from bending and collapsing. The building shells may have a layer of foam plastic insulation to provide thermal and acoustical insulation that is light in weight. The buildings may have hollow shells formed by double shells to provide more strength and insulation to the structures. The spaces in the double shells may be filled with insulation including soil as insulation against fallout. Soil as insulation against nuclear radiation is defined as earth, which includes loam, clay, sand, and stones. Various double shell panel combinations are shown in my Patent No. 2,897,668.

The reinforcing metal and the concrete in the building shells may have continuity characteristics to tie and bond the structure portions together so they co-act to make a building a monolithic-like structure that is strong and free of open cracks.

When the building shells are made of precast panels, metal fasteners such as clevises and eyes may be used in the panel edging to engage the reinforcing and to form pin connections to interlock adjoining panels, which, along with keying the joints with grout, maintains continuity across splices to provide means to maintain a smooth flow of stresses through the shells. FIGS. 19 and 20 show typical splices that have clevises and eyes that are pinned together to provide such continuity to the reinforcing and keying grooves in the panel edging to provide means to key the panels together with grout.

The clevis pin connections allow quick, accurate and secure alignment and joining of panels at erection, while the small weight of the thin precast panels allows the use of low cost, small load capacity erection equipment. A low cost portable utility crane such as the monorail gantry crane described in my Patent No. 2,763,218 may be used by a two-man crew to erect a small building.

Buildings B, C, D, E, and the like, may be built at low cost with unskilled labor due to standardized, relatively fool-proof construction means which include a modular system. The flexible forms being a standardizing means for molding the various shaped panels, positioning and spacing the clevis and eye fasteners, spacing, prestressing and anchoring the reinforcing.

In general, buildings B, C, D, and E, as illustrated in the drawings, have ribs or curved panels that have an arc of four feet eight inches across the panel width and four feet across the chord width. The tapered width panels in the dome-like building C are four feet wide at their base. The precast panels may generally be made about eight feet long like other types of building panels, so they may be shipped and handled with conventional equipment. The panels may be tapered in thickness to suit loading conditions. The depths of the corrugations of the panels may be varied so as to increase or taper the depths to suit loading conditions.

The curved panels may have a standardized crescent-like transverse section having identical curvatures on the convex and concave surfaces. The identical curvature allows panels to be cast at low cost by casting one such panel upon the other. The identical curvature also allows identical panels to nest tightly together when stacked, permitting low cost storage, shipping, and handling of stacks of panels without much danger of breakage of the panels. In addition, standardized identical curvature allows panels to be laminated to increase the shell thickness where additional shell thickness is needed for strength or insulation. Laminating allows a thin vapor barrier to be sandwiched between two precast panels.

Curved panels with a constant vertical thickness are stronger panels than those with a constant radial thickness having the same amount of aggregate. The panel having identical curvature is thickened towards its center, where it tends to be weakest against bending loads, and it thins out towards the side edge portions. The side edge portions are strong when joined to the adjacent panels, since the edge portions form strong V-shaped rib-like shell portions. Standardized curved panels may have a constant thickness that is, constant in a radial direction. This type thickness is suitable for use when codes require a large concrete covering of the reinforcing strands, such as one inch, for example. For this example, such code requirements would require a minimum panel thickness of slightly more than two inches. The bottoms of panels having constant thicknesses radially can be molded by casting the panels upon panel-like forms and by shaping the panel tops by scraping them with a curved screen.

Thin shells five-eighths of an inch thick have been used in other countries, since curved thin shell arches do not rely to a great extent on the reinforcing as does flat concrete slab construction. In the near future, thin shell construction is likely to be classified differently in construction codes so it may be made with thinner covering than is required for flat slabs, thus allowing the reduction of the dead load of such thin shell spans, therefore eliminating an enormous waste of building material, allowing people in this country to build blast resistant buildings on equal terms with those of other countries.

The standardized precast panels may be made with the standardized fasteners anchored in the panel edges. Such anchored fasteners may be used along with wire mesh fabric reinforcing, as described in my Patent No. 2,920,475.

The side edge portions of the adjoining curved panels form a V-shaped valley, as shown in FIG. 20. The V that is shaped by the adjoining curved panels tends to act as a rib, giving strength to the shell.

The V-shaped valleys can handle the flow of torrential rainfalls. The buildings may have gutters near the ground level to carry off the water drained from the building shell. Excessive snows, particularly heavy wet snows, would tend to slide off the arched spans. Slush would tend to slide off the arched shell rather than to dam-up and cause pools of water to form, thus the arched shell is unlike flat roofs that leak due to slush damming up. The curved panels are able to bend slightly from the expansive force of ice forming in the V-shaped valleys. The V-shaped valleys eliminate the need for conventional roof gutters and downspouts, thus eliminating troublesome members that are not easily accessible to service when they clog up with debris and ice. Any rain water that might penetrate the arched span from cracks caused by abnormal forces would tend to flow down the inside of the arch rather than to drip onto furnishings in the intermediate portions of a room. Such seepage may be controlled so it does little damage by providing screened weep holes through the floor slab to allow the seepage as well as scrub water to flow down into the duct-like air spaces below the floor. The weep holes may also be used as outlets for heating, venting and air-conditioning. The floor framing may form duct-like spaces, such as those shown in FIGS. 21, 22, and 24. The duct-like

spaces allow economical heating, venting and air-conditioning. The use of double shells of floors, walls and roofing as ducts is described in Patent No. 2,897,668.

The buildings do not have objectionable roof coverings that can corrode, nor coverings that can dry out, warp or buckle from the heat of the sun. The buildings do not have objectionable roof coverings such as shingles, slate or tile that can be torn loose by hurricane-like winds and blasts. The noise of rain or hail falling on the corrugated concrete shells would be less than that for metal roofs and the like.

Building B illustrated in FIGS. 1 to 4 inclusive offers a low cost, pleasingly attractive house that has great security means. The building also has means for comfort and convenience, as the building can easily be kept clean and sanitary. The building would be adaptable to any climate. Such a building made of thin shell concrete makes optimum use of concrete with its small arched span and the strong shape to provide adequate strength and durability to the structure.

FIG. 18 shows a typical section through the corrugated shell, each of the bowed panels 1*a*, 1*b*, and 1*c* forming a corrugation. Windows 2 may be sheltered by dormers W. All the windows have dormers W. FIG. 4 is an enlarged view of a dormer W that is mounted on a broad dished end panel 3. A dormer W includes a fixed hood 4 and sectionalized, pivotally mounted, self-sealing shutter sections 5 and 6. The shutter sections 5 and 6 are shown closed in FIG. 4. They are shown substantially opened for the other dormers W shown in FIGS. 1, 2, and 3. The shutter sections 5 and 6 may be closed or be partially closed to insure privacy and to shield against undesirable elements. Such a dormer is described in detail in my Patent No. 2,897,668. The dormers may have hoods 4 without the shutter sections 5 and 6.

End doors 7*a* and 7*b* are closures for a doorway that allows an automobile to be moved into and out of the building. The rear doorway has a door 8. The curved canopy-storm door 9 is shown in a canopy position in FIG. 2, so it can provide shelter from rain while entering or leaving an automobile parked in front of the canopy. The canopy-storm door 9 may be pivoted down from the canopy position shown in FIG. 2 to a position like that shown in FIG. 13, to allow it to act as a blast resistant door to provide protection from explosions, hurricane winds or the like. The front entrance F has an overhanging roof to provide shelter from rain while entering or leaving an automobile that is parked in front of it. The front entrance F has a vestibule. Exterior storm doors 10*a* and 10*b* can be closed during bomb raids, storms, floods, and the like. Gutters 11 take the rain that flows off the shell of the building.

The vent-like units 12 on the ridge of roof may be used as outlets for smoke, fumes, and exhausted air. A vent-like unit 12 may be used as an inlet for fresh air. Such a unit 12 may have a hinged vent cap to allow access means through the vent-like opening to the roof, thus during sudden floods, occupants could escape to the roof and be safe above the flood waters. A light-weight removable foldable platform similar to a child's play-pen (not shown) may be attached to the roof near a vent 12 for use as a sun deck, or as a safety deck during floods. A suspended floor such as that shown in my Patent No. 2,897,668 may be hung from the roof arch. The suspended floor may be used for storage space and in floodable areas, as a flood refuge. Such a floor may also support equipment such as an air-conditioner.

Building B may have partitions made of thin corrugated precast panels. Some of the panel partitions may be foldabel so room space in the building may be selectively varied to make multi-purpose room space. Such partitions are shown in Patent No. 2,897,668.

Building B may be built on a flat concrete slab base, the flexible forms being used to mold keying grooves in the slab and to space and position fasteners to interlock the building shell to the slab.

Building B may have floating foundation like the combination shown in FIG. 21. Such a foundation may be built on moist soil since it resists water penetration and it distributes the building load over a large area below the building. The floating foundation would be superior to the slab base.

Building B may have a basement story. Such a building may have framing like the framing shown in FIG. 24 and FIG. 24*a*. The basement would be suitable as a bomb shelter and as a shelter against fallout, particularly when the floor duct system above the basement story is filled to an extent with dense matter such as soil.

The dome-shaped building C, shown in FIGS. 5 to 8 inclusive, has a substantially hemispherical shape. The building has limited space but it provides maximum security from blast forces, because it has a very strong shape for the amount of material in its shell. FIG. 8 shows the canopy-storm door 9*a* positioned to act as a storm door. Building C may have a basement similar to the one described for building B. The ceiling for the basement would be substantially hemispherical in shape with tapered corrugations like the roof portion of the shell. Such a strongly shaped basement ceiling may support a thick mass of earth to insulate against nuclear radiation. Building C has similar characteristics to those of building B. In addition, the shell of building C has more bracing means. The building C would be useful as a blast resistant shelter, an earthquake resistant building, a low cost vacation-refuge cottage, a low cost tourist cottage, or the like. The front entrance H is similar to the front entrance F of building B.

The two story building D, shown in FIGS. 9 to 13 inclusive, has more headroom on the second floor than would a gabled roof with equal draining characteristics. Building D is similar to building B. It may have a basement. Canopy-storm doors 9 and awning-shutters 13 are pivoted down to act as strong closures during severe storms and the like, as shown in FIG. 12 and FIG. 13. Dormers W are used in the second story. FIG. 11 shows a dormer W mounted on a typical side panel corrugation, the shutters of the dormer are closed. The front entrance J is like the front entrance F of building B. The doors 7*c* and 7*d* are similar to doors 7*a* and 7*b* of building B. The collar 14 is arched over the doors 7*c* and 7*d* to shelter the doorway from rain draining from the shell above it. The collar 14 would act as a dam for soil when the building is covered with a layer of soil during warlike times. A one story building may be constructed similar to building B and at a later period the second story may be added, the arch spanning the first story being incorporated into the second floor supporting structure.

The building E, shown in FIGS. 14 to 17 inclusive, is not as strong as the arched buildings previously described, but it is more functional than conventional types of rectangular buildings of equal cost. Building E may have a basement similar to the one described for building B, it would differ from the arrangements shown in FIGS. 24 and 24*a*, because building E has vertical wall portions into which an arched lower story ceiling would frame. Building E would be suitable for use as a multiple dwelling structure, also as a non-dwelling structure such as an office or shop building. The building E may be used as a motel structure or as an institutional building. A short building similar to building E may be used as a single family house.

Building E would be an ideal structure for a motel, since it incorporates the following means to make a motel profitable. It is pleasingly attractively modern, strong, low in cost to build and maintain, fire-safe and thus suitable for rural areas, it can easily be kept clean and sanitary, free of vermin and other pests. The partitions and exterior walls may be of double shell sound-proof con-

struction. Self-sealing doors and windows may be closed to provide a large degree of thermal and acoustical insulation, floor vents and duct-like spaces below the floor being means to economically heat, vent, and air-condition the structure. The vent units **17** are similar to vent units **12**.

The strong overhanging roof at the front of the building offers shelter for people when they are unloading and loading their automobiles as well as for sheltering the front of the motel and automobiles from the sun, snow and rain. The front doors **8***a* and the front windows **2***a* and **2***b* are sheltered by the overhanging roof. The rear windows **2***c* and end windows **2***a* have awning-shutters **13***b* and **13***a*, respectively, that act as awnings when raised and act as hurricane shutters and the like when lowered. The curvature of the shell corrugations from almost horizontal at the roof to vertical at the rear of the building, allows rain water to flow over the rounded edge of the roof without it arching out from the building shell.

The corrugated roof panels **15** act as beams and the vertical wall panels **16***a* and **16***b* act as columns. The vertical panels are much stronger in resisting side pressure than would block walls using the equivalent materials. The horizontal panels **15** are highly efficient as simple beams and the like, since the thick center portion of the corrugation is near the extreme top, thus it can better resist high compressive forces. The reinforcing wires near the side edges of the corrugations resist tensional stresses. The reinforcing and the corrugated shapes prevent objectionable cracking. The corrugated front, rear and roof panels may be combined to act like rigid frames. The narrow end panels **18** may be hollow to provide stiffness to the shell.

FIG. 18 is a typical sectional view showing bowed panels **1***a*, **1***b*, and **1***c* forming a portion of the thin shell of building B. The shell portion shown in FIG. 18 may be merely an outer shell, as a hollow or double shell may be used to provide more strength and insulation for the structure. FIG. 18*a* shows a double shell that may be formed by adding a second shell to the combination shown in FIG. 18. Shell portions of buildings C, D, E, and the like, would be similar to the portion shown in FIG. 18. The combination shown in FIG. 18*a* has the outer shell panels **1***a*, **1***b*, and **1***c* connected to the inner shell panels **45** with connecting members **46**. Members **46** may be placed continuously or be intermittently spaced. Insulation **47** may be placed in the space between the inner and outer shells. Insulation **47** may be earth to provide a high degree of insulation from nuclear radiation, in addition to insulation to reduce the passage of sound and heat. Common light-weight insulation materials may be used to provide thermal and sound insulation where insulation from nuclear radiation is not required. When the spaces between the shells are not filled with insulation, they may be used as ducts for heating and ventilation. Bleeder holes may be made in the panels **45** to allow air to pass through the inner shell.

FIG. 19 shows a typical field splice such as that for interlocking the ends of two curved panels or the edges of two flat panels. The panels **1***g* and **1***h* have reinforcing strands or wires **19**. A fastener or clevis **20** is connected to the wire **19** in panel **1***g* and a fastener or eye **21** is connected to the wire **19** in panel **1***h*. The clevis **20** and the eye **21** are interlocked by inserting a pin **22**. The pin **22** may be tapered to allow it to be driven to tension or prestress the reinforcing where it spans the joint. The pin **22** may be threaded so a nut may hold it securely. Threaded pins **22** may be longer than shown, so they may also act as fasteners to connect laminated sections, intersecting walls, and other structural or utility members. A strand of reinforcing wire **19***a* may be placed in the joint. It may be inserted in the crotch of the clevis **20**. Grout **23** is inserted in the joint during erection of the panels or later to key the panels **1***g* and **1***h* together. The grout **23** may have iron particles in its mix to cause the grout to swell to maintain its volume, thus compensating for the shrinkage tendencies of the concrete. The flexible forms have means to tension the wires **19** before casting the panels. Wires **19** may be coated with a yieldable covering before the casting, so the concrete will not adhere to them. The wires **19** may be slackened while the flexible forms are being stripped. After the flexible forms are removed from a panel, the wedges **24** may be driven by the shop or field crew to retention the wires **19**.

The ends of the reinforcing strands may be welded together if preferred to make a low cost connection of the panels.

FIG. 20 shows a typical joint or splice formed by joining the side edge portions of the bowed or corrugated panels **1***k* and **1***m* to form a V-shaped valley. The metal fastening means and grouting are similar to those shown in FIG. 19. Additional reinforcing wire **19***b* and the like may be placed in the joint.

When the reinforcing wire **19** and the fasteners **20** and **21** are thin and easily bent, wedges (not shown) may be lightly driven between the panels to tension the metal spanning the joint. The wedges may be removed after grout **23** has been added to the joint and has been allowed to cure. When the metal is easily bent, bars or washers may be used along with temporary bolts through the joints to pull the panel faces into alignment. The bars or washers would be flat for the joints such as that shown in FIG. 19, and they would be angle-iron members for the V-shaped shell portion shown in FIG. 20. The aligning means along with means to prevent fresh grout from seeping out of joints is clearly described in my Patent No. 2,897,668.

FIG. 21 is a fragmentary sectional view through an arched thin-shell structure such as that of buildings B and C. The building shell has panels **1***p* that are corrugated like the shell portion panels shown in FIG. 18. The structure may have a double or hollow shell like that described previously.

The building shell below the floor line forms an inverted arched shape. The inverted arch has the same characteristics as the arch of the upper portion of the structure. The lower portion of the shell forms a strong, light-weight, water-resistant, floating foundation that distributes the weight of the building over a large area of the soil **25**. Pressure of the soil **25** and hydrostatic pressure against the convex surfaces of the panels **1***p* compress the inverted arch of the shell, thus squeezing cracks closed to seal against water penetration. The inverted arching of the bottom of the building shell makes a more efficient, durable, water-resistant foundation than that shown in my Patent No. 2,897,668.

Panels **26** may be placed above the panels **1***p* to form a double or hollow shell having oval shaped duct-like spaces in the lower portion of the structure. Such oval spaces allow air to be circulated adjacent to the bottom of the structure to eliminate dampness. The oval spaces would provide access crawl space for cleaning and waterproofing maintenance work. The floor slab panels **27** may have reinforcing like that of the panels **1***g*. The panels **27** are shown supported by the supports **28**. The space between panels **26** and **27** may be used to circulate air **29** under the floor of the shelter. The structure may have an air duct from the ground level to these duct-like spaces. The floor panels **27** may have spaced bleeder holes **27***a* through them to allow fresh air to be inserted into the shelter. The fresh air may be conditioned to heat or cool it.

When dampness is not a problem, the panels **26** may be omitted, the bottom panels **1***p* and the supports **28** supporting the panels **27**.

Gutter sections **30** may be attached to the building shell. The gutter sections **30***a* may be hinged to sections **30**. The hinging action allows movement of the section when ice forms in the gutter. Sections **30** and **30***a* may be com-

bined where freezing weather never exists. The gutter sections would be omitted when the structure is built underground or in a trench and covered with soil.

The structure illustrated in FIG. 21 would be suitable for use as a bomb shelter and the like. When such structures are to be subjected to great soil pressures, the corrugations in the arches may be tapered in depth to suit the loading conditions.

Corrugated arched shells similar to the structure shown in FIG. 21 may be used as tunnel passageways to bomb shelters and the like. Such structures may also be used as tunnel-like snow-sheds for railroads and highways, also as arches to span roadways, to provide shelter for the roadway from landslides.

When buildings B, C, D, E, and the like, are to have a single thin shell, they should have an electrical conduit system that does not have to be embedded in the shell, since large embedded conduits would weaken the shell. Therefore, I have provided a safer and lower cost conduit system than that of conventional small buildings. Conduit-like assemblies T are shown attached to the inside of the building shells in FIGS. 21 and 24. The conduit assemblies T are shown positioned high enough to clear occupants and doorways.

FIG. 23 shows an enlarged cross-sectional view of an assembly T. The inverted trough-shaped conduit **31** is supported by wall brackets **32**. The conduit **31** may be an aluminum or plastic extrusion, which may have sloping fins to support wires. The center portion of the conduit **31** may be thick enough to tap for bolts to hold wires, outlets, outlet sockets, and switches. The bottom closure may be sectionalized strips **33**. The strips **33** may be fastened to conduit **31** with pivot bars **34**. The ends of bars **34** engage the grooves in conduit **31**. The bar **34** has a slotted head pin that is keyed to it; the pin is turned to pivot the bar. Switches, outlet connections including outlet sockets, may be attached to the inside of the conduit **31**. Strips **33** may be cut to suit these outlets. Switches may have long chains to reach down to a suitable position for people to pull them. Extension plugs may hang from sockets in the conduit. Thus extension cords may be kept above the floor for safety. Children and pets cannot readily reach these dangerous cords or the outlets. In case of a short circuit in an appliance, the appliance cable can be yanked out of its socket. Flood waters and water used in cleaning cannot readily reach these highly positioned conduits and cause short circuits. Lamps, pictures and drapes may be hung from the conduit **31**. Additional wires and outlets can readily be added to the conduit **31** as the inside of the conduit is easily accessible. The conduit **31** may also carry water pipes.

FIG. 24 is a fragmentary sectional view taken through a two story arched building which has a thin corrugated shell. The second floor framing and the framing above the second floor may be similar to the framing shown for a similar building in Patent No. 2,897,668. Floor slab panels **27***b* form the second floor. The framing shown in FIG. 24 is, in general, like the framing shown in FIG. 21. FIG. 24*a* is similar to FIG. 24, it differs by the lower floor being for a basement story with the upper story having a floor near the ground level. Second story panels **1***v* are similar to panels **1***p*. The gutter **30***b* is at ground level, adjacent to the floor panels **27***b*.

FIG. 24*b* is a transverse sectional view through the lower story ceiling and the floor above it. FIG. 24*b* shows the transverse curvature of the cementitious panels **48** and the insulation **47** between the floor and ceiling. The insulation **47** is earth which would screen out nuclear radiation. Vertical members **49** may be used to connect the floor and ceiling.

FIG. 25 shows typical panel combinations for allowing the thin shell buildings with corrugated shells to be adapted to various conditions. Panel **35** is laminated to a panel **36**, which is a typical arrangement for a shell of double thickness. A coating of asphalt or the like may spread on the contact surfaces before laminating, to act as a vapor barrier. Panel **37** is fastened across the chord of a panel **36**. The segmental space at panel **37** may be used as a duct for air or piping and wiring, or it may be filled with insulation, or concrete. Segmental rib **38** is a typical rib for bracing across a corrugation, or for blocking across a corrugation. Rubs **38** may be used when possible severe loads require such bracing. Tie rod **39** may be connected to the reinforcing in the V-joints, to tie across the corrugations to prevent the corrugation from spreading, if the shell is subject to possible severe loads. Rods **39** may be embedded in a groove in the bottom of ribs **38**. Panel **40** is a panel that is half as wide as panel **36** and the like. Panel **41** has a flattened S-shape, or serpentine shape. Panel **42** has V-shape similar in shape to a winged bird.

Panels **36** and **43** with spacers **44** form a double shell with space between. The space may be used for insulation or ducts. Panels **43** may have bleeder holes **43***a* to allow air to pass through them when the duct-like spaces are used for air-conditioning, heating and ventilation. The space between the shells may be filled with concrete, thus thin precast panels may be used as forms in place of temporary forms for poured-in-place concrete construction. The thin shells besides acting as forms provide a neat exterior for the structures. This method would be particularly suitable for thick arched structures, such as large bomb shelters as well as arched bridge spans.

Existing buildings that are inflammable or weak against side thrusts from blasts such as atomic explosions, or are not modern looking, may be covered with a strong durable thin corrugated concrete shell similar to the shells of buildings B, C, D, and E.

Thus it will be seen that I have provided a novel corrugated building suitable for low cost building projects or for shelters against natural or war caused violent forces.

While I have illustrated and described several embodiments of my invention, it will be understood that these are by way of illustration only, and that various changes and modifications may be made within the contemplation of my invention and within the scope of the following claims.

I claim:

1. A fixed shelter supported on land for protection against violent warfare forces, comprising at least an outer, thin shell means, said shell means having an intermediate roof portion, a floor in contiguous relationship with opposing portions of said shell means to form a substantially total enclosure therewith, said shell means comprised substantially of cementitious material, reinforcing strand means of material for resisting tensional and shearing forces embedded in said shell means, said shell means having a multiplicity of corrugations arranged in uniformly spaced relationship, the side edges of each of said corrugations being in contiguous relationship with those of adjoining corrugations throughout substantially their entire lengths, each of said corrugations having an outwardly bowed arcuate curvature across substantially its entire width, said shell means being at least two stories high, having a lower story and an upper story, at least said lower story being below the ground line, said lower story having a cementitious, arched, thin shell ceiling spanning the interior of said shelter, said ceiling having arched ceiling corrugations that are connected to said corrugations in said shell means, each of said arched ceiling corrugations having an outwardly bowed arcuate curvature across substantially its entire width, said bowed curvature of each of said arched ceiling corrugations being bowed outwardly from said lower story, said upper story including a second floor in spaced, opposed relationship with and above said ceiling, and the intermediate space between said ceiling and said second floor having a filler of earth disposed therein.

2. A shelter as recited in claim 1 wherein said shell means includes substantially vertical, exteriorly exposed wall portions.

3. A shelter as recited in claim 1 together with an inner corrugated shell in spaced relationship with at least said intermediate roof portion of said outer shell means, said outer, thin shell means and said inner shell being connected together at spaced intervals to cause them to coact, said inner shell means being comprised substantially of cementitious material.

4. A shelter as recited in claim 1 wherein said shell means has a bottom portion underneath said floor, said bottom portion being arched downwardly.

5. A shelter as recited in claim 1 wherein said intermediate roof portion of said shell means is an upwardly arched span, and wherein said corrugations in said upwardly arched span have their longitudinal axes bowed upwardly.

6. A shelter as recited in claim 3 together wtih a filler of earth disposed in the space between said outer, thin shell means and said inner shell.

7. A shelter as recited in claim 3 wherein said intermediate roof portion of said shell means is an upwardly arched span, and wherein said corrugations in said upwardly arched span have their longitudinal axes bowed upwardly.

8. A shelter as recited in claim 5 wherein said intermediate roof portion of said shell means has a substantially hemispherical shape, and wherein the width of each of said corrugations is progressively smaller in an upward direction.

9. A shelter as recited in claim 5 wherein said reinforcing strand means includes at least fiber glass.

10. A shelter as recited in claim 5 wherein said shell means has a bottom portion underneath said floor, said bottom portion being arched downwardly.

11. A shelter as recited in claim 7 together with a filler of earth disposed in the intermediate space between said outer, thin shell means and said inner shell.

12. A shelter as recited in claim 10, wherein said shell means has a shape in a horizontal plane at either of said floors that is elongated with substantially semi-circular ends, said shell means having along a transverse section taken in a vertical plane, outwardly curved end portions, substantially all of said corrugations having a substantially constant width, said longitudinal axes of said corrugations in said arched span being bowed upwardly across the width of said shelter, said corrugations at the said ends being progressively decreasing in height.

References Cited in the file of this patent

UNITED STATES PATENTS

2,166,577	Beckius	July 18, 1939
2,215,773	Workman	Sept. 24, 1940
2,257,153	Blaski	Sept. 30, 1941
2,353,071	Pitou	July 4, 1944
2,365,145	Neff	Dec. 12, 1944
2,372,200	Hayes	Mar. 27, 1945
2,425,883	Jackson	Aug. 19, 1947
2,469,603	LeTourneau	May 10, 1949
2,499,478	Feser	Mar. 7, 1950
2,616,149	Waller	Nov. 4, 1952
2,704,983	Dronkelaar	Mar. 29, 1955
2,755,630	Freyssinet	July 24, 1956
2,897,668	Graham	Aug. 4, 1959
2,921,463	Goldfein	Jan. 19, 1960

FOREIGN PATENTS

517,548	Great Britain	Feb. 1, 1940
487,472	Italy	Dec. 2, 1953
713,574	Great Britain	Aug. 11, 1954
157,748	Sweden	Feb. 5, 1957
961,303	Germany	Apr. 4, 1957

OTHER REFERENCES

Engineering News-Record, p. 103, Oct. 21, 1943.
Civil Engineering, February 1953, pp. 37–39.