PATENT SPECIFICATION

(11) 1 588 328

1 588 328

(21) Application No. 41755/77 (22) Filed 7 Oct 1977
(44) Complete Specification published 23 April 1981
(51) INT. CL.³ F16F 7/12
(52) Index at acceptance
F2S CM

(72) Inventors ROBERT JAMES BRICMONT
PHILIP ANTHONY HAMILTON
RAYMOND MING LONG TING

(19) THE PATENT OFFICE LONDON

(54) KINETIC ENERGY ABSORBING PAD

(71) We, H. H. ROBERTSON COMPANY, a corporation organised under the laws of the Commonwealth of Pennsylvaina, of Two Gateway Center, Pittsburgh, Pennsylvania 15222, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention relates to kinetic energy absorbing pads, and more particularly to pads having a core which, under the force of an impact load, is adapted to undergo stepwise deformation, thereby to reduce significantly the peak dynamic load sustained by the pad.

Nuclear energy plants, nuclear fuel processing plants as well as other process plants incorporate pipes and conduits for conveying fluids under a broad range of pressures. Of particular concern are the extremely high pressure conduits. Should a fracture occur in such a conduit, particularly adjacent to a conduit elbow, the issuing high pressure fluids produce a jet force which whips the broken conduit at an extremely high velocity. An enormous impact load is applied by the whipping conduit to the first stationary object in its path. Absorption of the kinetic energy of such high velocity conduits is achieved by devices known as pipe whip restraint pads. The pad incorporates a core which is crushed by the impact load. Absorption of the kinetic energy is achieved by crushing, that is wrinkle buckling the core elements. Energy asborbing honeycomb structures are known in the art, see for example, U.S. patent 3,130,819 (A.C. Marshall); 3,552,525 (C. R. Schudel).

The principal objects of this invention are:

To provide an impact load sustaining pad which sustains buckle-initiating peak load significantly less than those sustained by prior art pads;

To provide an impact load sustaining pad which avoids the single, relatively high, buckle-initiating peak required to overcome the high column or strength of prior art honeycomb cores.

To provide an impact load sustaining pad incorporating deformable elements providing stepwise absorption of the kinetic energy of the impact load;

To provide an impact load sustaining pad wherein the number, the axial length, the thickness and the profile of the profiled sheet metal elements may be varied, the pads thereby being adapted to absorb the kinetic energy of a broad range of impact loads;

To assembly a crushable core from a plurality of individual cellular units which undergo axial buckling independently of each other during energy absorption, whereby the core has a predictable energy absorbing capacity.

According to this invention there is provided a pad adapted to sustain an impact load by stepwise absorption of the kinetic energy of the impact load, comprising a face plate adapted to be positioned transversely of and in confronting relation with an impact load; a base plate spaced-apart from and substantially parallel with said face plate; and a crushable core positioned between said face plate and said base plate and adapted to buckle under the force of an impact load, said core including first and second sets of profiled sheet metal elements having corrugations and which are assembled to provide individual metal cellular units extending normal to said face plate and which buckle independently of each other under the force of an impact, characterised in that said elements present end faces adjacent to one of said plates which faces reside substantially in a first common plane extending generally parallel with said one said plate, the elements of the first set present second end face adjacent to the other said plate which second end faces reside substantially in a second column plane extending generally parallel with said other said plate, and the elements of the second set present third end faces spaced apart from said other said plate which third end faces reside substantially in a third common plane extending between and generally parallel with the first and second common planes, said face plate being adapted to distribute the force of an impact load initially to said elements through the first and second end faces and subsequently and simultaneously to said elements through the first and third end faces, whereby said pad will sustain sequential peak loads each significantly less than the single peak load which would be sustained if the profiled elements presented second and third end faces in a common plane.

The arrangement is such that the pad sustains two or more separate peak dynamic loads. The first peak load corresponds to that load required to initiate buckling in the first set of profiled elements. As the first set of profiled elements buckle, the sustained load decreases until the face plate engages the third end faces. At this time the pad experiences a second peak load which is a composite of that load required to initiate buckling in the second set of profiled elements, and that load required to continue buckling the first set of profiled elements. Thereafter the sustained load decreases to a minimum and increases again to a constant applied load wherein the first and second sets of profiled elements undergo plastic deformation.

Where all of the profiled elements are of the same thickness or gauge, the second peak load is greater than the first peak load — the second peak load being a composite of that load required to initiate buckling of the second set of the profiled elements and that load required to continue buckling of the first set of profiled elements. To reduce the second peak load, the second set of profiled elements may be formed from lighter gauge material. For example, if the first set of profiled elements is formed from 12 gauge material, the second set of profiled elements may be formed from 14 to 16 gauge material. The reduction in the second peak load is attributed to a reduced buckle-initiating peak load for the lighter gauge second set of profiled elements.

Further in accordance with this invention, the core may comprise groups of profiled elements. The end faces of the elements of each group are stepped or tiered whereby a plurality of peak loads are encountered, one for each additional set of the profiled elements.

The invention is further described, by way of example, with the aid of the accompanying drawings, wherein,

Figure 1 is a view schematically illustrating a pipe whip restraint pad positioned adjacent to a high pressure conduit;

Figure 2 is a view similar to Figure 1 illustrating the mode of absorbing the kinetic energy of the broken high pressure conduit;

Figure 3 is a cross-sectional plan view of the present pad taken along the line 3–3 of Figure 4;

Figure 4 is a cross-sectional view taken along the line 4–4 of Figure 3;

Figure 5 is a cross-sectional view taken along the line 5–5 of Figure 4;

Figure 6 is a fragmentary isometric view of a profiled sheet metal element useful in the present pad;

Figure 7 is a fragmentary isometric view of a metal cellular unit assembled from a pair of the profiled elements of Figure 6;

Figure 8 is an end view of the crushable core assembled from a plurality of the metal cellular units of Figure 7;

Figure 9 is an end view of the core of Figure 8;

Figure 10 is a fragmentary isometric view of a pair of metal cellular units formed from different gauge materials;

Figure 11 is an end view of another metal cellular unit useful in the present crushable core;

Figure 12 is a graphical presentation of the general relationship between applied load and the deformation of a crushable core;

Figure 13 is a graphical presentation similar to Figure 12 comparing the load versus deformation curve of the present unit and a prior art unit;

Figure 14 is a graphical presentation similar to Figure 12 illustrating the kinetic energy absorbing capability of the present pad as a function of sheet metal gauge;

Figure 15 is a graphical presentation similar to Figure 12 illustrating the kinetic energy absorbing capability of the present pad as a function of the number of metal cellular units in the crushable core;

Figures 16 and 17 are end and side views, respectively, of an alternative arrangement of the present crushable pad;

Figure 18 is a graphical presentation similar to Figure 13 illustrating the load versus deformation curve of the crushable core of Figure 16 compared with a prior art unit;

Figure 19 is a fragmentary isometric view of a metal cellular unit useful in the crushable core of Figure 16, wherein the profiled elements are of a different gauge thickness;

Figure 20 is a graphical presentation, similar to Figure 18, illustrating the load versus deformation curve produced by employing the metal cellular units of Figure 19;

Figure 21 is an end view of a further alternative embodiment of the present crushable core;

Figures 22 and 23 are end and fragmentary isometric views, respectively, wherein the profiled elements present plural offset ends; and

Figures 24 and 25 are end and side views, respectively, wherein the end faces of each group of profiled elements are stepped or tiered.

Referring to said drawings, Figure 1 schematically illustrates a pipe whip restraint pad 35 of this invention secured to a suitable support such as a structural column 36. The pad 35 includes a face plate 37, a base plate

38 spaced apart therefrom and parallel thereiwth, and a crushable core 39 extending between the plates 36, 38. The pad 35 is positioned adjacent to an elbow 40 of a high pressure conduit 41. The high pressure conduit 41 conveys high pressure fluids in the direction of the arrow 42. Thus positioned, the pad 35 is adapted to restrain the whipping action of the conduit 41 and to absorb the kinetic energy thereof, should a crack, such as illustrated in dotted outline at 43, develop in the conduit segment 44 downstream of the elbow 40.

Should the conduit 41 fracture at the location 43, the issuing high pressure fluids provide a jet force represented by the arrow 45 in Figure 2, which whips the conduit 41 at a high velocity and with enormous kinetic energy against the face plate 37. The line of action of the jet force 45 is indicated by the arrow 46 in Figure 2.

The kinetic energy of the high velocity broken conduit is absorbed by wrinkle buckling of the elements of the crushable core 39. The crushable core 39 sustains multiple peak loads each of which is significantly less than the peak load sustained by prior art devices. Thus the structural strength requirements of the structural column 36 or other suitable pad support is significantly less than that required when using prior art devices.

Referring to Figures 3 through 5, the pad 35 may include an interior perimeter wall 47 secured to the base plate 38, and an exterior perimeter wall 48 secured to the face plate 37. The perimeter wall 48 is positioned in telescoping relation with the interior perimeter wall 47. As best shown in Figure 5, the interior perimeter wall 47 presents a perimeter face 49 which confronts the interior face of the face plate 37. The perimeter face 49 is spaced-apart from the face plate 37 by a distance indicated at 50. During energy absorption, such as illustrated in Figure 2, the face plate 37 is displaced through the distance 50. The distance 50 may vary from about 25 mm to about 400 mm.

The present crushable core is formed from a plurality of elements, such as the profiled sheet metal element 51 illustrated in Figure 6. The sheet metal element 51 presents alternating crests 52 and valleys 53 connected by inclined webs 54. The profiled sheet metal elements 51 preferably are assembled in valley-to-valley relation and secured together by plural tack welds 56 to provide a metal cellular unit 55 such as illustrated in Figure 7.

Referring to Figures 8 and 9, the crushable core 39 provides first means, e.g. plural first metal cellular units 55A, for absorbing a portion of the kinetic energy; and second means, e.g. plural second metal cellular units 55B, for absorbing substantially the balance of the kinetic energy. The metal cellular units 55 are assembled with the crests 52 (Figure 8) thereof in engagement. Plural fasteners 56 extend through the valleys 53 and secure the plural metal cellular units 55 together as a unitary assembly. Spot welds 57 provide additional securement for the metal cellular units 55.

As best shown in Figure 8, each of the metal cellular units 55 presents plural parallel cells 58. In addition, the adjacent ones of the metal cellular units 55 provide additional longitudinal cells 59. The cells 58, 59 have longitudinal centre lines 60, 61, respectively.

In accordance with the present invention, the first metal cellular units 55A are of unit length, whereas the second metal cellular units 55B are of a length less than unit length. The first and second metal cellular units 55A, 55B, preferably are alternately presented. As best shown in Figure 9, the sheet metal units 51A and 51B present coplanar first end faces 62. The sheet metal elements 51A present second end faces 63 whereas the sheet metal elements 51B present third end faces 64. The third end faces 64 are inwardly offset from the second end faces 63 by an increment indicated at 65. It will be observed in Figure 5 that the core 39 is positioned such that the longitudinal centrelines 60, 61 of the cells 58, 61 (Figure 8) are normal to the face plate 37. The crushable core 39 (Figure 4) presents the first end faces 62 adjacent to the base plate 38, the second end faces 63 adjacent to the face plate 36, and the third end faces 64 inwardly spaced-apart from the face plate 37. The significance of the incremental offset of the third end faces 64 relative to the second end faces 63 will become apparent later in the specification. As will also become apparent later in the specification, the pad 35 includes distributing means, e.g. the face plate 37, for distributing the force of the impact load initially to the first means (the first metal cellular units 55A); and subsequently and simultaneously to the first means and to the second means (the second metal cellular units 55B).

All of the elements 51 of the metal cellular units 55A and 55B may be formed from the same gauge sheet metal. Sheet metal gauges in the range of 12 to 16 gauge have been found suitable for the present purposes. Alternatively, the sheet metal elements 51A and 51C (Figure 10) of the first and second metal cellular units 55A, 55C may be formed from sheet metal of different thicknesses. Preferably the second metal cellular unit 55C — the shorter metal cellular unit — is formed from a lighter gauge sheet metal. The metal cellular units 55A, 55C preferably are alternately presented when assembled to provide a crushable core 39A.

Figure 11 illustrates a crushable core 39B comprising plural metal cellular units 55D each assembled from profiled sheet metal elements 51D whose profile differs from the sheet metal elements 51 of Figure 6. The sheet metal elements may take any suitable profile.

A general relationship between the applied load and the core deformation is graphically presented in Figure 12. The solid line 66 represents the ideal load versus core deformation curve. The dotted line 67 represents a typical load versus core deformation curve of prior art pads.

It will be observed that in the ideal curve 66, the applied load increases rapidly to the plastic deformation stage 68 during which the core deforms essentially uniformly at a constant load 69. The typical curve 67 departs drastically from the ideal curve 66, in that it reaches a peak load 70 which is considerably higher than the constant load 69. The peak load 70 corresponds to that load required to initiate wrinkle buckling of the crushable core. Following the peak load 70, the typical curve 67 falls to a load level 71 below the constant load 69 and then rises essentially to the constant load 69. It will be appreciated that the relatively high peak load 70 sustained by the restraint pad also must be sustained by the pad support.

The pipe whip restraint pad 35 of the present invention completely avoids the relatively high peak loads sustained by prior art devices during their use or during their manufacture. In Figure 13, the solid line 72 represents an idealized applied load versus core deformation curve for the pipe whip restraint pad 36 illustrated in Figures 3 through 5. As can be seen from Figures 3 and 4, the crushable core 39 contains five metal cellular units 55, three units 55A of unit length and two units 55B of a length less than unit length. It will be observed in Figure 13 that the crushable core 39 sustains a first peak load 73 which is considerably less than the peak load 70 of conventional restraint pads. The peak load 73 corresponds to the buckle-initiating load of the three first metal cellular units 55A. Thereafter, the sustained load reduces to a lower load level 74. At this point, the face plate 37 (Figure 4) contacts the third end faces 64 of the second metal cellular units 55B. The sustained load increases to a second peak load 75. The second peak load 75 is a composite of that load required to initiate buckling in the second metal cellular units 55B and that load required to continue buckling of the first metal cellular units 55A.

Following the peak load 75, the sustained load reduces to a second lower load level 76 and then rises to a plastic deformation stage or load 77. The present restraint pad 35 undergoes a greater amount of deformation to reach the plastic deformation stage 77 than does the typical prior art pad — compare deformation lengths L^1 and L^2. Notwithstanding the greater deformation length L^2, the present pad drastically reduces the peak load sustained by the pad and, hence, sustained by the pad support.

The second peak load 75 is greater than the first peak load 73. The second peak load 75 may be reduced to a level substantially equal to that of the first peak load 73 — see peak load 75A (Figure 13) — by utilizing the arrangement illustrated in Figure 10 wherein the profiled elements 51C of the second metal cellular units 55C are formed from lighter gauge sheet metal.

The energy absorbing capacity of the present restraint pad 35 varies with the sheet metal gauge. Specifically, the lighter the gauge the less the energy absorbing capacity. In Figure 14, the curve 72 corresponds to the crushable core 39 wherein the profiled sheet metal elements thereof are formed from 12 gauge metal. The curves 78, 79, of reducing energy absorbing capacity, correspond to crushable cores utilizing profiled sheet metal elements formed from 14 gauge and 16 gauge metal respectively.

The energy absorbing capacity of the present restraint pad 35 also varies with the number of metal cellular units employed. Specifically, the greater the number of units, the greater the energy absorbing capacity. It will be observed in Figure 15 that the curve 72 corresponds to five unit core 39 of Figures 3 to 5. The curve 80 corresponds to a three unit core and has a reduced kinetic energy absorbing capacity. The curves 81, 82 and 83 correspond to 7, 10 and 15 unit cores having increasing kinetic energy absorbing capacity.

Alternative embodiments of the present crushable core are illustrated in Figures 16 through 25.

Figures 16 and 17 illustrate a crushable core 39C comprising a plurality of metal cellular units 55E. Each of the metal cellular units 55E comprises one of the profiled sheet metal element 51A and one of the profiled sheet metal elements 51B. The crushable core 39C presents a first set of profiled elements, that is the elements 51A; and a second set of profiled elements, that is the elements 51B. The second set of profiled elements presents third end faces 64 which are inwardly offset from the first end faces 63 of the first set of elements 51A by an incremental distance indicated at 65 (Figure 16).

Figure 18 diagrammatically illustrates the applied load versus core deformation curve identified by the number 84 of the crushable core 39C. It will be observed that the crushable core 39C sustains a first peak load 85 and a larger second peak load 86. Both of the peak loads 85, 86 are significantly less than the corresponding peak load 70 of a typical prior art pad.

Figure 19 illustrates a metal cellular unit 55F assembled from one profiled sheet metal element 51A and one lighter gauge profiled sheet metal element 51E. The sheet metal element 51E corresponds, in length, to the shorter sheet metal elements 51B of Figure 16. A plurality of the metal cellular units 55F may be assembled to provide a crushable core 39D which generates the applied load versus core deformation curve 84A graphically illustrated in Figure 20. Since the lighter gauge sheet metal elements 51E require a lower buckle-initiating peak load, it will be observed in Figure 20 that the core 39D sustains a second peak load 87 which may be substantially the same as the first peak load 85 but which is significantly less than the peak load 86 sustained by the crushable core 39C of Figure 16. Thus the second peak load may be reduced by utilizing thinner gauge elements as the second set of profiled sheet metal elements.

Another method of reducing the second peak load is to utilize sheet metal elements of different column strengths. Figure 21 illustrates a metal cellular unit 55G assembled from sheet metal elements 51B and 51D. A plurality of the metal cellular units 55G may be assembled to provide a crushable core 39E, wherein the first set of profiled sheet metal elements corresponds to the elements 51D, and wherein the second set of profiled sheet metal elements corresponds to the elements 51B. It should be evident that the greater depth of the elements 51D attributes greater column strength to these units. The shallower depth of the elements 51B attributes a lesser column strength to these units. A further reduction in the second peak load may be achieved by forming the elements 51B from a lighter gauge sheet metal.

Figures 22 and 23 illustrate a further alternative crushable core 39F assembled from a plurality of metal cellular units 55H. As best shown in Figure 23, the webs 53 of each of the metal cellular units 55H are cut on a bias as at 88, whereby each metal cellular unit 55H presents the second end faces 63 and the inwardly offset third faces 64.

Figures 24 and 25 illustrate a further alternative crushable core 39G assembled from plural groups 89 of profiled sheet metal elements 51A, 51B, 90, 91 and 92 of decreasing lengths. The profiled elements 51A, 51B, 90, 91, 92 of each group 89, present first end faces 62 adjacent to the base plate 38; a second end face 63 adjacent to the face plate 37; and third end faces 64, 93, 94 and 95 spaced-apart from the face plate 37 by successively larger distances 96 through 99, respectively. The arrangement is such that the face plate 37 is adapted to distribute the force of an impact load initially to the profiled element 51A through the first and second end faces 62, 63 thereof, and subsequently and successively to the other profiled elements 51B, 90, 91 and 92 through the first and third end faces 62, 64, 93, 94 and 95 thereof, whereby the pad sustains plural peak loads.

WHAT WE CLAIM IS:—

1. A pad adapted to sustain an impact load by stepwise absorption of the kinetic energy of the impact load, comprising a face plate adapted to be positioned transversely of and in confronting relation with an impact load; a base plate spaced-apart from a substantially parallel with said face plate; and a crushable core positioned between said face plate and said base plate and adapted to buckle under the force of an impact load, said core including first and second sets of profiled sheet metal elements having corrugations and which are assembled to provide individual metal cellular units extending normal to said face plate and which buckle independently of each other under the force of an impact, characterised in that said elements present end faces adjacent to one of said plates which faces reside substantially in a first common plane extending generally parallel with said one said plate, the elements of the first set present second end faces adjacent to the other said plate which second end faces reside substantially in a second common plane extending generally parallel with said other said plate, and the elements of the second set present third end faces spaced apart from said other said plate which third end faces reside substantially in a third common plane extending between and generally parallel with the first and second common planes, said face plate being adapted to distribute the force of an impact load initially to said elements through the first and second end faces and subsequently and simultaneously to said elements through the first and third end faces, whereby said pad will sustain sequential peak loads each significantly less than the single peak load which would be sustained if the profiled elements presented second and third end faces in a common plane.

2. A pad, as claimed in claim 1, further characterised in that the second and third end faces are provided by each of said profiled elements.

3. A pad, as claimed in claim 1, further characterised in that the second and third end faces are provided by separate ones of said profiled sheet metal elements.

4. A pad, as claimed in claim 1 further characterised in that the second and third end faces are provided by separate ones of said metal cellular units.

5. A pad, as claimed in claim 1 further characterised in that said third end faces are spaced-apart from said other siad plate by successively larger distances.

6. A pad, as claimed in any of said claims 1-5, further characterised in that the thickness of the profiled sheet metal elements of said second set is less than that of the profiled

sheet metal elements of said first set.

7. A pad adapted to sustain an impact load by stepwise absorption of the kinetic energy of said impact load, substantially as herein described with reference to the accompanying drawings.

8. A crushable core for a pad as claimed in claim 1-5, said core being adapted for stepwise absorption of the kinetic energy of an impact load, said core including profiled sheet metal elements which are assembled in pairs to provide individual metal cellular units which undergo axial buckling independently of each other under the force of said impact load, characterised in that

the elements of a first set and a second set present first end faces residing substantially in a first common plane extending normal to the axial length of said elements;

the elements of said first set have opposite second end faces residing substantially in a second common plane generally parallel with said first common plane;

the elements of said second set have opposite third end faces residing substantially in a third common plane positioned between and extending generally parallel with said first common plane and said second common plane.

9. A structure protected against dynamic impact loads from a source of anticipated dynamic impact loads, characterised in that

a pad, as claimed in any of said claims 1-5, is secured to said structure in confronting relation with said source of anticipated dynamic impact loads.

ROYSTONS
Chartered Patent Agents
Tower Building
Water Street
Liverpool L3 1BA
Agents for the Applicants

Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1981. Published at the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1588328 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

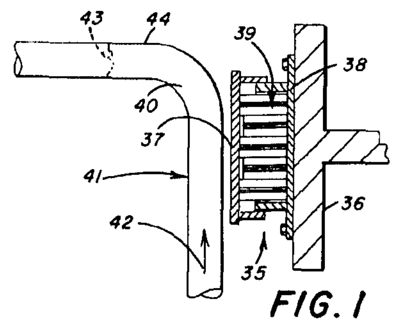


FIG. 1

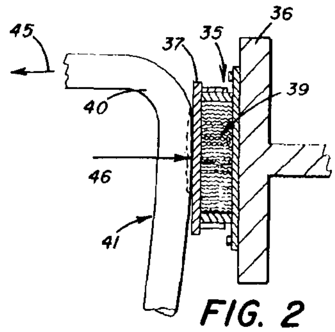


FIG. 2

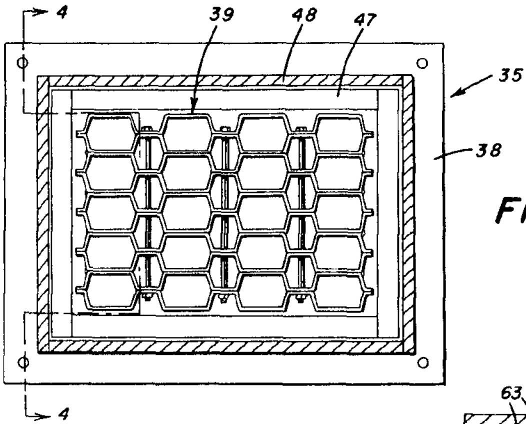
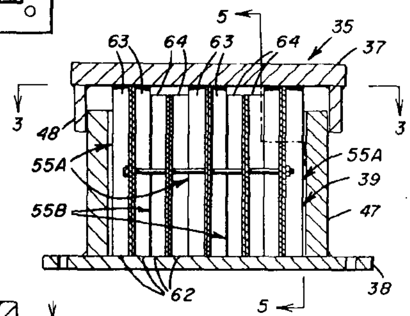


FIG. 3

FIG. 4



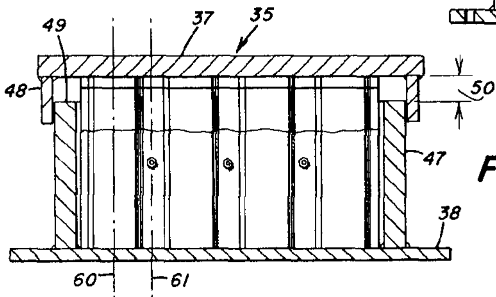


FIG. 5

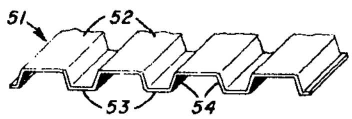


FIG. 6

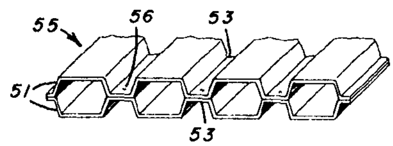


FIG. 7

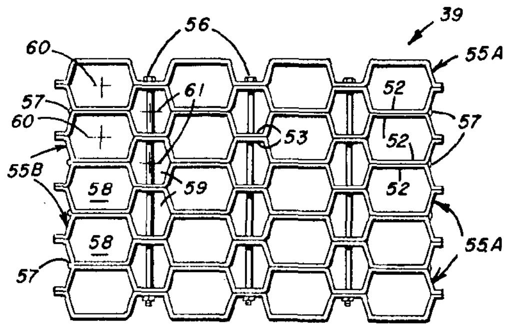


FIG. 8

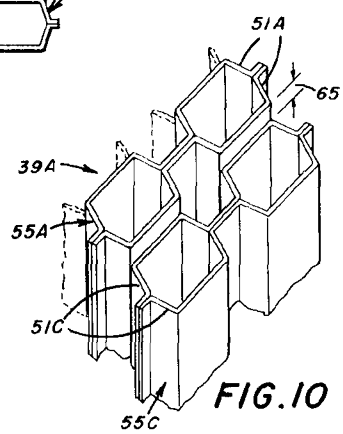


FIG. 10

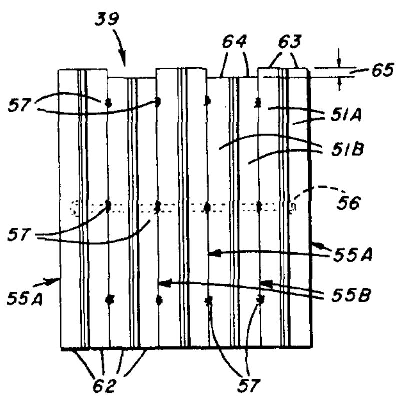


FIG. 9

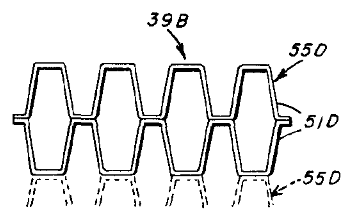


FIG. 11

1588328 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

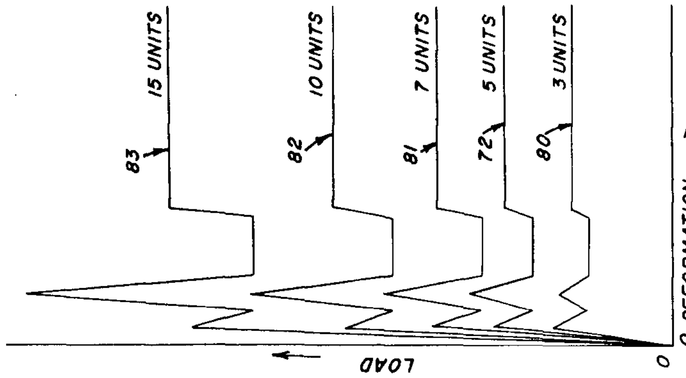


FIG.15

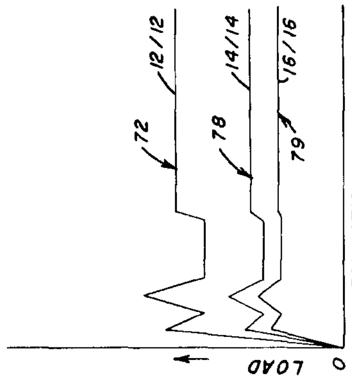


FIG.14

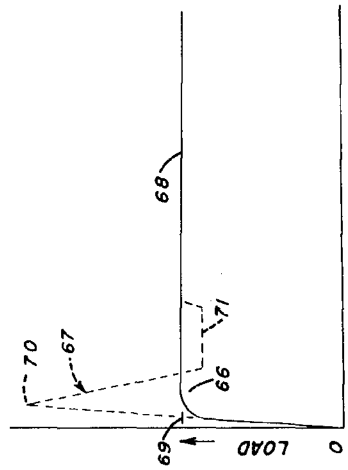


FIG. 12

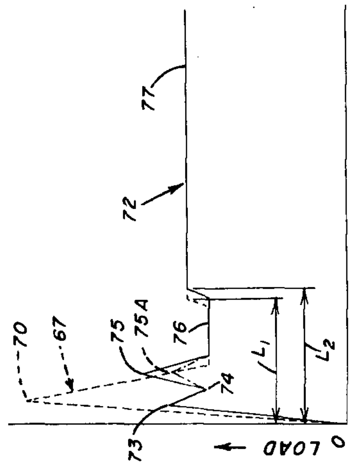


FIG.13

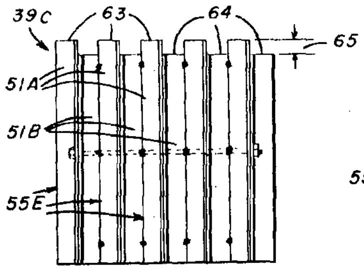


FIG. 16

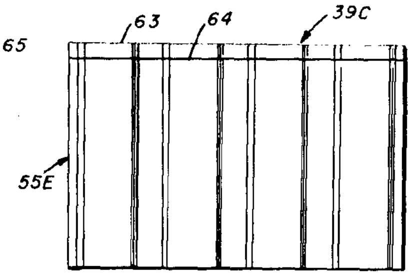


FIG. 17

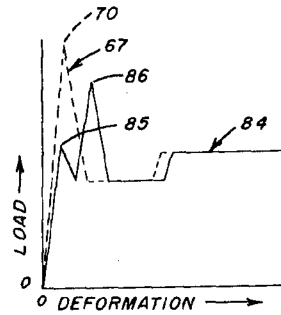


FIG. 18

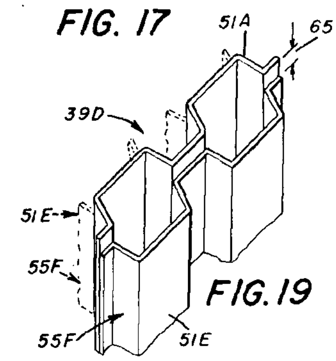


FIG. 19

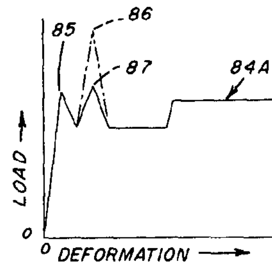


FIG. 20

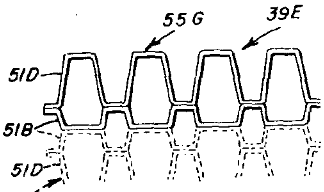


FIG. 21

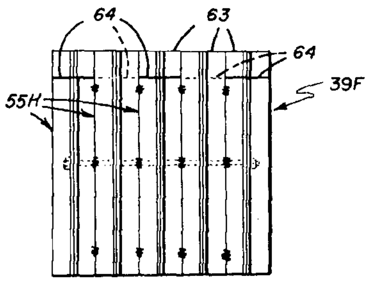


FIG. 22

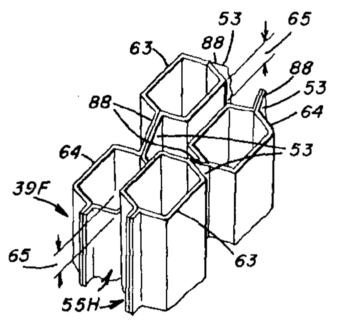


FIG. 23

1588328 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 5

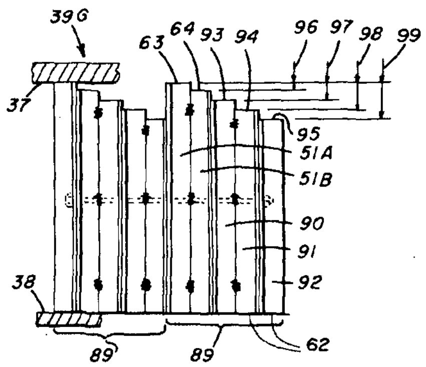


FIG. 24

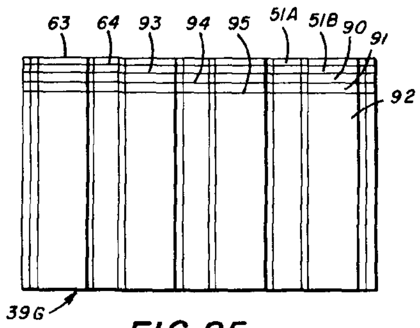


FIG. 25