Feb. 3, 1959 H. G. SIMPSON ET AL 2,871,997

LOW PITCH RIGID FRAME BUILDING

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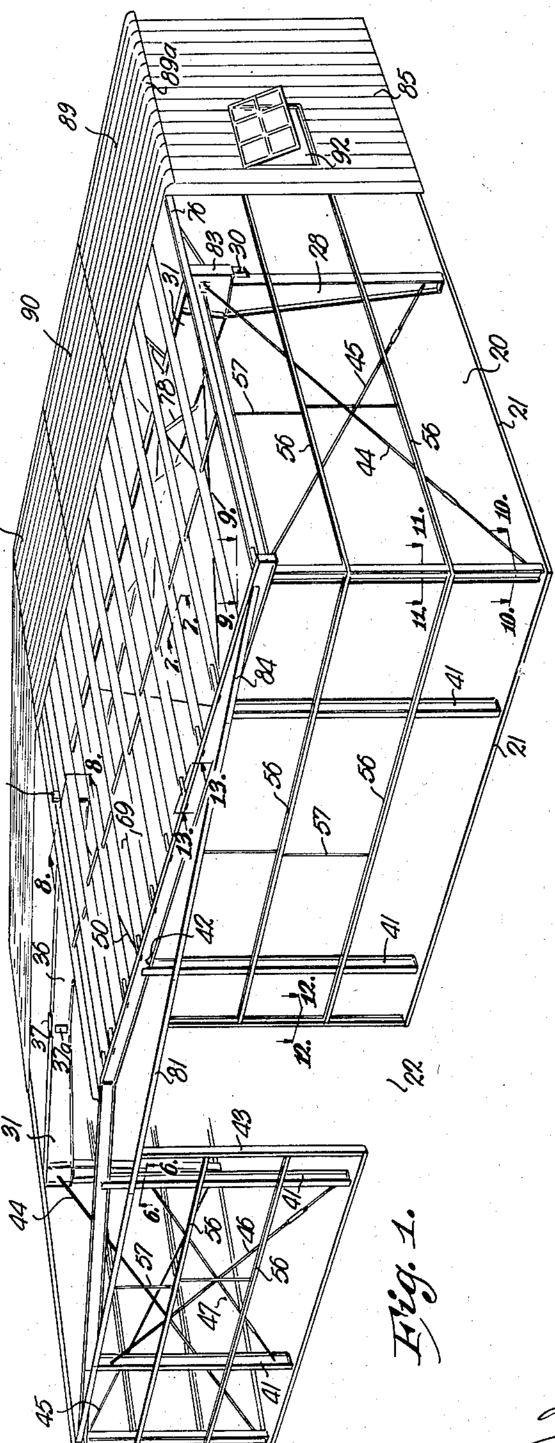

Fig. 1.

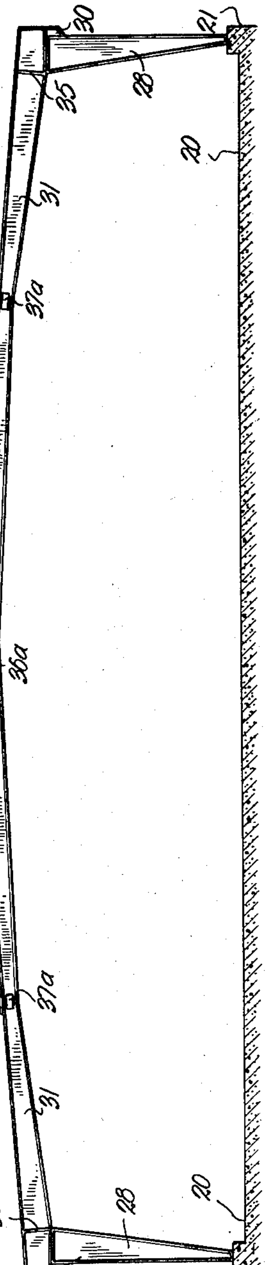

Fig. 2.

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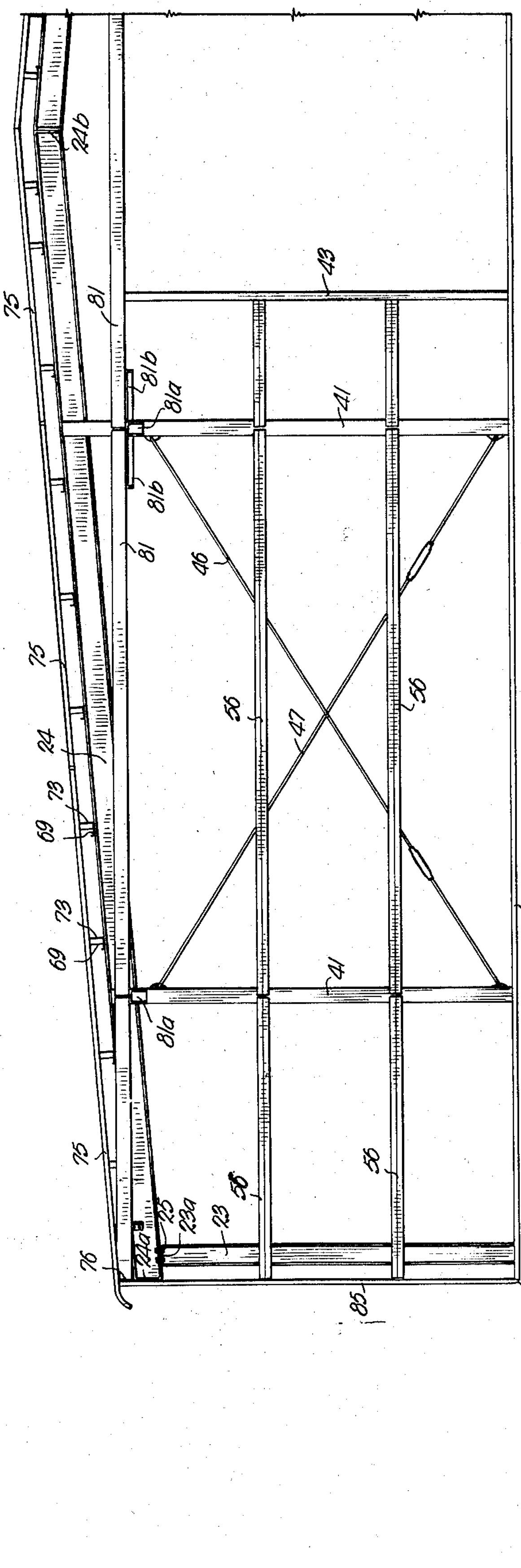

Fig. 3.

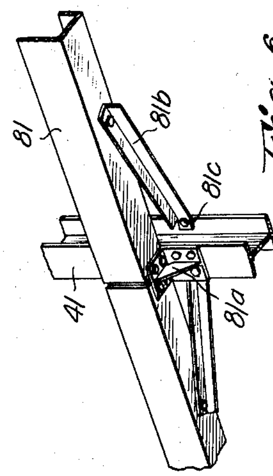

Fig. 6.

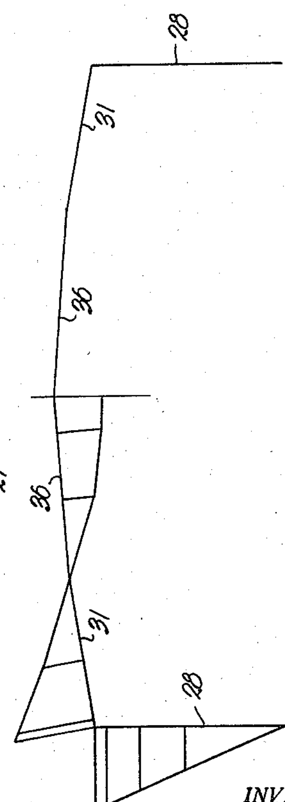

Fig. 5.

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LOW PITCH RIGID FRAME BUILDING

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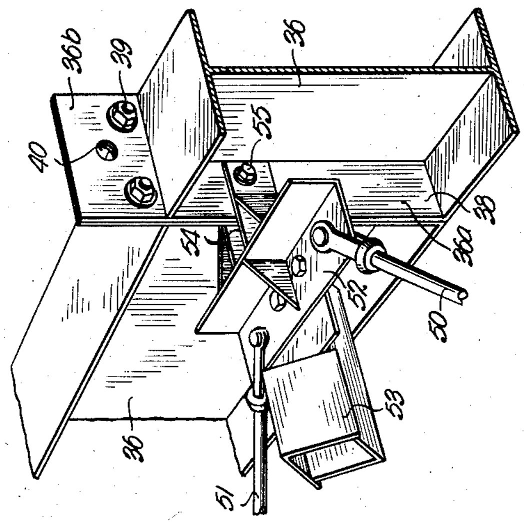

Fig. 8.

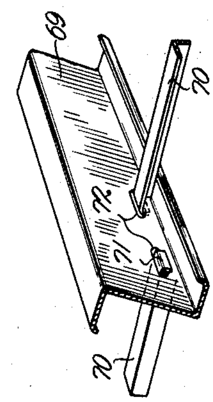

Fig. 7.

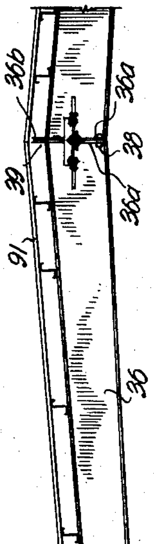
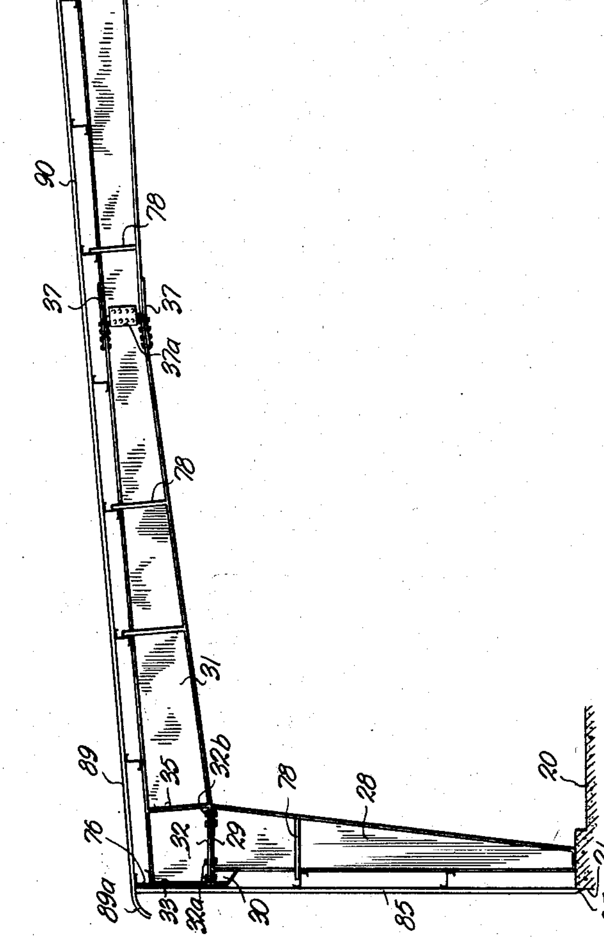

Fig. 4.

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LOW PITCH RIGID FRAME BUILDING

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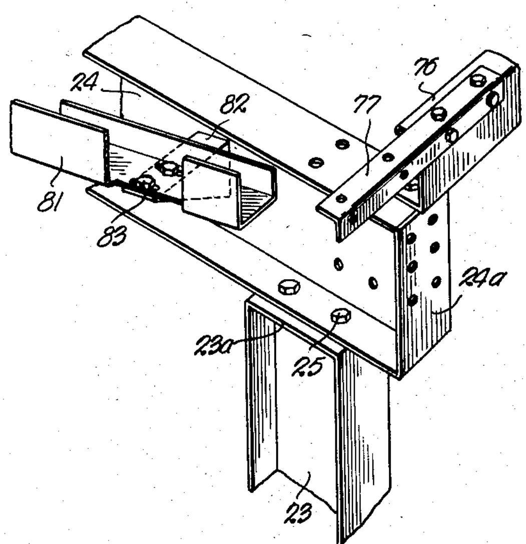

Fig. 9.

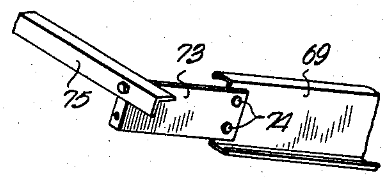

Fig. 13.

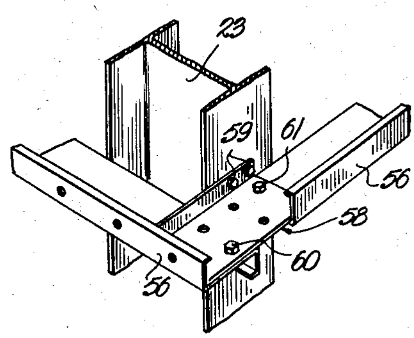

Fig. 11.

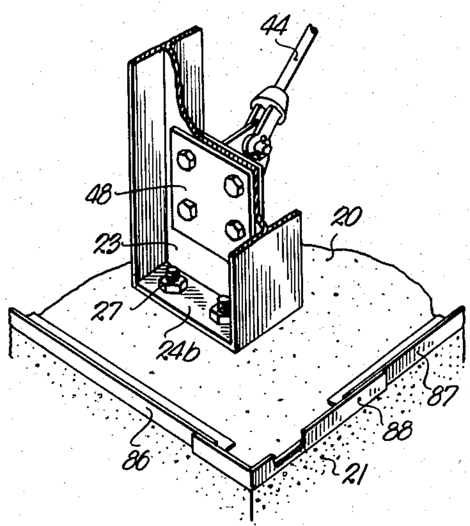

Fig. 10.

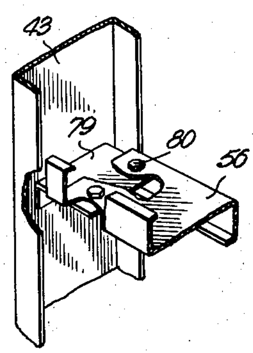

Fig. 12.

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LOW PITCH RIGID FRAME BUILDING

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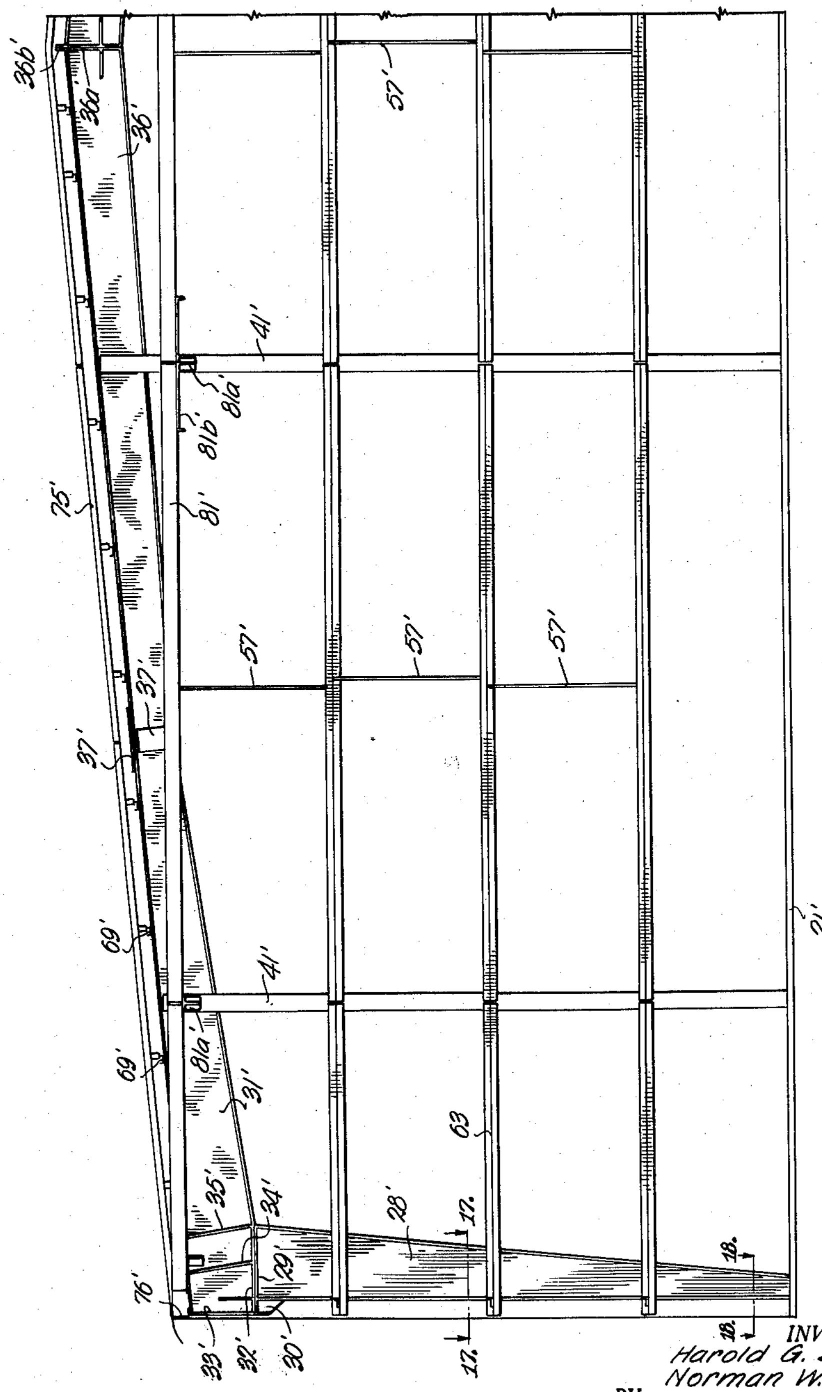

Fig. 14.

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LOW PITCH RIGID FRAME BUILDING

Filed June 11, 1957 6 Sheets-Sheet 6

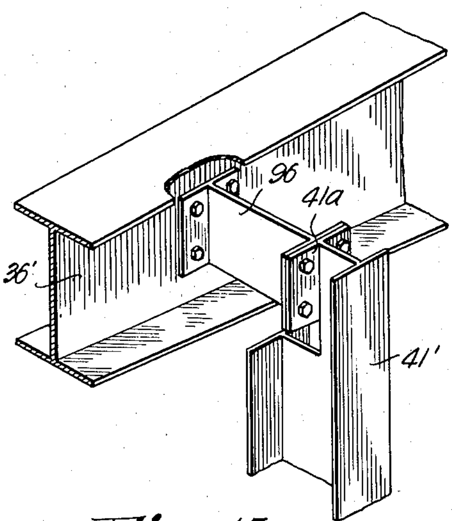

Fig. 15.

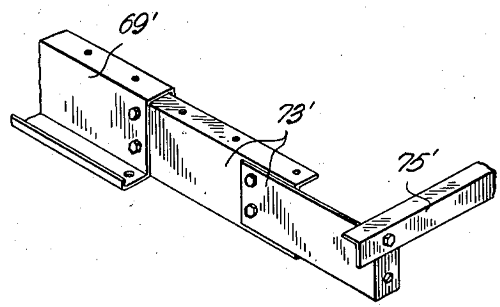

Fig. 16.

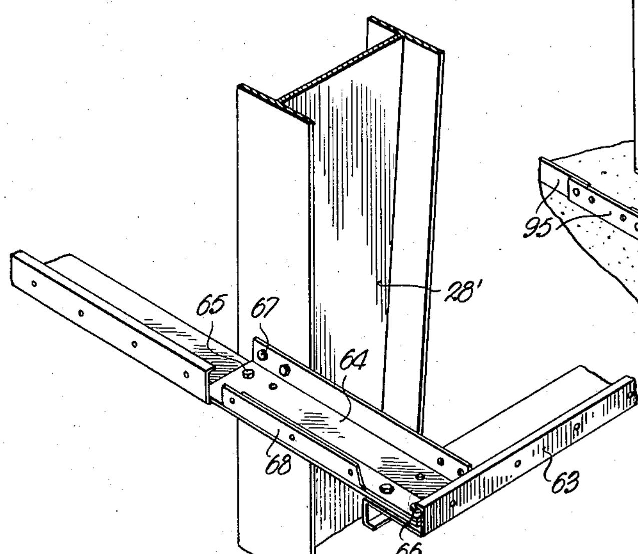

Fig. 17.

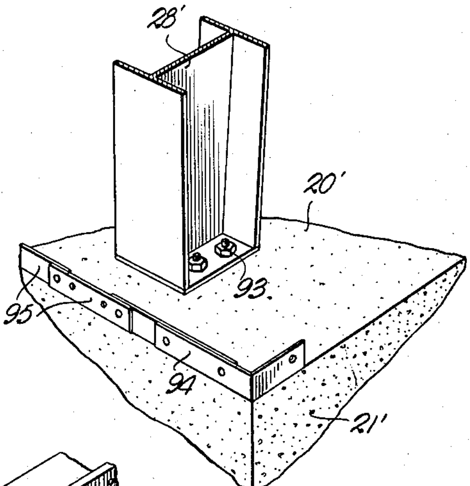

Fig. 18.

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United States Patent Office

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2,871,997

LOW PITCH RIGID FRAME BUILDING

Harold G. Simpson, Raytown, and Norman W. Rimmer, Independence, Mo., assignors to Butler Manufacturing Company, Kansas City, Mo., a corporation of Missouri

Application June 11, 1957, Serial No. 665,026
3 Claims. (Cl. 189—1)

This invention relates to rigid frame buildings and the construction thereof and refers more particularly to low pitch rigid frame buildings comprising one story gable bents of rigid frame construction wherein a raftered roof structure is built integrally with wall columns.

This invention is an improvement over and further development of application Serial No. 558,084, filed January 9, 1956, entitled "Column and Rafter Assembly for Rigid Frame Buildings," inventors Roger A. Hield and Carmen L. Ramirez, now Patent No. 2,815,831, patented December 10, 1957.

Rigid frame structures

A rigid frame building is one which is structurally stable by virtue of the rigidity of its joints, as differentiated from a trussed structure which is stable because of the triangular arrangement of its members. Rigid frame structures of this type are now quite common and in many building applications have replaced the ordinary roof truss and column structures of past times. The various frame members of a rigid frame structure are generally referred to as the column, the rafter and the knee. The knee is that area or joint at the eave which connects the column and rafter members together. The knee ties the structure together and makes it a unit to carry all loads whether they be vertical loads on the roof or lateral loads on the vertical projection of the building.

Rigid frames are arches in their action and they produce a lateral thrust at their bases. In truss-type frames this thrust is not very great and can usually be carried by the ordinary type of floor and footing construction. The rigid frames can be made fixed or free (hinged) at their column base. A hinged column base keeps foundation costs at a minimum and is therefore generally preferable. Rigid frame structures belong to a general class of structures called continuous structures. This term is applied because the structural action and stress travel are continuous throughout the structure, there being no joints in the structural sense. Because of this, the entire structure must be stress analyzed as an integral unit and cannot be considered as an assembly of separate members.

Rigid frame types of buildings are essentially merely an enclosing shell around the necessary functions of the building and the structure itself uses up little of the enclosed building volume. Such a construction contributes to economy and the useable interior dimensions always govern the outside dimensions of the building. A rigid frame building requires a height from two to five feet less (depending upon span) than that required by comparable truss and column construction. The structural frame of buildings of this type when erected and placed present a very rigid type of construction even before the enclosing walls are in place. The structure is very pleasing to the eye in that it is clean and clear cut. The absence of the usual maze of steel members found in a truss-type construction is notable.

Rigid frame buildings are designed for live and wind loads plus dead load. Dead load is the weight of the

building itself. Live load can be any load that can be applied to the building but is usually thought of as snow load and is considered as acting vertically over the horizontal projection of the room. Wind load is also a live load but is considered separately because the wind load is considered to act horizontally on the vertical projection of the building. Wind tunnel tests show that the wind load on buildings will vary for each different size and shape and that the wind load will act as a pressure on the windward side and as a vacuum on the leeward side of the building.

The principal stresses of a rigid frame are due to bending. The shears and thrusts are of little consequence except that the direct compression in the column and roof beams is usually an appreciable stress. The knee is the strongest section of the frame. This condition is required by vertical load considerations, but at the same time gives the frame a very great lateral strength. Since the knee is always the section requiring the greatest strength it has greater depth than any other point in the frame. The structural performance of the knee section is rather complex in that there is a sudden change in the direction of stress in traveling around the sharp corner between the column and the rafter members. However, the design of the knee has been well established on a rational basis by a considerable number of tests, some of them relatively large sized members. These tests indicate a nonlinear stress distribution around the corner with the neutral axis displaced toward the inside corner of the knee.

It should be especially pointed out that in every rigid frame or arch, no matter what the size or configuration of the column and rafter members, there is a moment diagram which has certain features common to all. This diagram consists in (assuming the column hinged at the base) a moment increasing up the column uniformly to the knee joint where there is a change of direction into the roof beam. This moment in the column is a negative one with the inside of the column under compression and the outside of the column under tension. The neutral axis where there is no compression nor tension runs up the center line of the column. Starting at the roof beam or rafter at the knee joint there is a maximum negative moment which decreases to zero at some point before the center point or ridge of the building which then becomes positive until the ridge. The point of zero moment in the rafter is called the point of inflection. While the moment diagram for any given structure can be modified by changing the stiffness of the various members at various places, nevertheless, this general pattern is constant although the point of inflection may shift.

Rigid frame structural members

In the rigid frame buildings of conventional construction, the main frame members are generally L-shaped column and rafter members, the L-shaped members being used in opposed pairs which are joined at the ridge of the roof. In such L-shaped members, the web is preferably widest at the junction between the column and the rafter since this is the point at which the load and stresses are the greatest. The column tapers downwardly from this point and the rafter likewise tapers toward the ridge, all in accordance with good engineering design.

A few manufacturers of prefabricated buildings make the entire L-shaped member (one column and its attached rafter) as a single integral unit. However, this presents a tremendous storage problem at the factory, not to mention the problem of shipping such units to the site where the building is to be erected. Accordingly, it is more common practice to make this member in two parts which are assembled at the job site.

In such a conventional two-piece construction, one of the parts is a conventional I-beam section and the other is an elbow-shaped "column and haunch" section, the two being joined by a bolted or riveted splice plate. This is the situation in the W. B. Larkin et al., Patent No. 2,263,214, entitled "Rigid Frame Building," issued November 18, 1941. This is a material improvement but the "column and haunch" section still is a cumbersome unit to store and ship. Also, since different builders have different ideas about what the wall height of their building should be (which means that the column portion must be made longer or shorter, according to the builder's requirements), the factory must maintain a variety of sizes of "haunch" sections, each size being specially designed and engineered at no little expense.

A few manufacturers have endeavored to make the column and the rafter separate parts which are joined at the job site by means of a large splice plate, but this is the point of greatest load and strain, and, therefore, requires a big splice plate and a very large number of rivets or bolts to obtain the necessary strength. On the whole, this arrangement is not very popular or satisfactory with the manufacturers.

In the Hield and Ramirez application Serial No. 558,084, above listed, a column and rafter assembly was provided wherein the column and rafter were separate, straight structural members formed to permit a stable, strong interconnection therebetween which was simple, small in size and required a minimum number of interconnecting bolts or rivets therebetween. This construction obviated the manufacturer having to store and ship elbow-shaped "haunch" sections.

The latter construction proved to be satisfactory for limited width buildings and buildings having a relatively steep pitch, say, in a ratio of one to six or the like. However, when it became desirable to construct extremely wide, low pitch, rigid frame buildings, pitch ratio of one to twelve, the construction provided therein proved to be unsatisfactory for a number of reasons. In the first place, it is well known that the lower the pitch of the building the higher the bending moment at the juncture between the column and rafter. It proved uneconomical or impracticable to insert enough bolts in the column-rafter juncture to carry the moment stress. In the second place, since it was desired to employ column and rafter members tapered to correspond to the areas of greatest moment it was found that as the width of the building increased, the tapering of the rafter members had to be much more gradual to provide a strong enough central joint and, thus, the construction provided little advantage over a uniform cross section I-beam. In either the uniform cross section I-beam or in such a uniformly tapered rafter member, it was discovered that there was excessive strength at points in which strength was not required, thus wasting material and, additionally, in the tapered member, there was relatively low central strength. Finally, it proved desirable to assemble the low pitch, wide, rigid frame building by first erecting the columns and then picking up the entire rafter member connected as one member centrally thereof and setting it on the columns to be attached thereto. A uniform cross section I-beam proved to be of greatly excessive weight (particularly because of the excess steel in the web) while a uniformly tapered member was of insufficient strength centrally thereof to permit such an operation. Other factors desired included the provision of a uniform roof line to permit fixing of rigid panel sheeting thereto and a relatively uniform rafter underside to permit fixing of an adequate ceiling thereto, as well as providing a building which could be completely and adequately weatherproofed both from vertical weather effects and from horizontal weather effects.

Therefore, an object of this invention is to provide a rigid frame, one-story gable bent of an extremely low pitch and of relatively great width wherein the column and rafter members are designed to provide the greatest practical efficiency in withstanding bending moment stress.

Another object of the invention is to provide such a rigid frame building wherein the structural support members may be erected by first setting up the columns and then lifting the previously connected rafter member upwardly as a unit, while suspending it from its center and setting it on the columns to be fixed thereto, the rafter member being sufficiently strong to withstand this central suspension while, as well, being of an absolute minimum weight to facilitate the operation.

Another object of the invention is to provide a column and rafter assembly for a low pitch, maximum width, rigid frame building of the one-story gable bent type wherein the column and rafter members are formed so as to provide the maximum resistance to bending moment stress yet wherein the roof line is uniform to permit application of straight sheeting thereto and the ceiling line is harmonious and simple to permit the application of a suitable ceiling.

Another object of the invention is to provide a low pitch, extremely wide, rigid frame building of the one-story gable bent type wherein a plurality of types of building end column and rafter members may be employed to minimize both in each member and the combination the quantity of metal required and the engineering required in the building while still providing an extremely strong and rigid building with all of the advantages both engineering-wise and appearance-wise of rigid frame buildings.

Yet another object of the invention is to provide a low pitch, extremely wide, rigid frame building of the one-story gable bent type, the construction of the utmost simplicity yet providing a completely weather-sealed construction against both vertical and horizontal weather effects.

Another object of the invention is to provide a low pitch, extremely wide, rigid frame building of great strength, rigidity, inside volume and weather tightness which is yet of the utmost simplicity and may be constructed at great speed and at a minimum cost.

Other and further objects of the invention will appear in the course of the following description thereof.

In the drawings, which form a part of the instant specification and are to be read in conjunction therewith, an embodiment of the invention is shown and, in the various views, like numerals are employed to indicate like parts.

Fig. 1 is a perspective view with parts broken away showing a wide span rigid frame building of the one-story gable bent type of the inventive construction.

Fig. 2 is a side view of one of the inventive column and rafter assemblies.

Fig. 3 is an end view of one form of the end of the building from the outside of the building, this form applicable to buildings wherein further expansion is not contemplated.

Fig. 4 is an enlarged side elevation of one of the column and rafter members of Fig. 2 as mounted as an intermediate member in the inventive rigid frame building.

Fig. 5 is a schematic diagram of the moment diagram of a column and rafter unit of one of the inventive buildings.

Figs. 6–11 are all detail views of parts of the construction shown in Fig. 1. All of the views are in the same perspective as Fig. 1, enlarged, in the direction of the arrows in Fig. 1. Fig. 6 is a view taken along the lines **6—6** of Fig. 1 in the direction of the arrows.

Fig. 7 is a detail view of one of the joints between the roof purlins and the sag angles of Fig. 1 as taken along lines **7—7** of that figure in the direction of the arrows.

Fig. 8 is an enlargement of the center joint of the inventive column and rafter assembly showing the attachment of the brace rods and struts to the center thereof as taken along the lines **8—8** of Fig. 1 in the direction of the arrows.

Fig. 9 is a detail view of the upper front right corner of the building of Fig. 1 taken along the lines **9—9** of Fig. 1 in the direction of the arrows.

Fig. 10 is a view of the lower right-hand front corner of the building in Fig. 1 taken along the lines **10—10** of Fig. 1 in the direction of the arrows.

Fig. 11 is a detail view of the joinder between the girts and the column in the right-hand front corner of the building of Fig. 1 taken along the lines **11—11** of Fig. 1 in the direction of the arrows.

Fig. 12 is a detail perspective view of the juncture between the lower girt and door post on the right-hand side of the door of Fig. 1 taken along the lines **12—12** of Fig. 1 in the direction of the arrows.

Fig. 13 is an enlarged detail view of one end of a roof purlin and the attached gable angle taken along the lines **13—13** of Fig. 1 in the direction of the arrows.

Fig. 14 is a side view of a second form of the end of the building from the outside thereof, this form particularly applicable to buildings wherein expansion is contemplated or the end wall is to be open.

Fig. 15 is a three-quarter perspective view of a connection between the roof beam and the end wall post of Fig. 14.

Fig. 16 is a three-quarter perspective view of a connection between a purlin and the gable angle of Fig. 14.

Fig. 17 is a three-quarter perspective view of the column and girt connection of Fig. 14. Fig. 17 is a view taken along the lines **17—17** of Fig. 14 substantially in the direction of the arrows.

Fig. 18 is a three-quarter perspective view of the positive column base, side and end wall floor members and floor of Fig. 14. Fig. 18 is a view taken along the lines **18—18** of Fig. 14 substantially in the direction of the arrows.

General building construction

Referring now to the drawings and more particularly to Fig. 1, numeral **20** indicates generally the flooring for the building which may conveniently be a poured concrete slab. The margin of the slab comprises a curb **21** having a downwardly extending edge which, in the construction shown, provides a sill **22** for the forward door. If it is desired that the floor **20** be below the top of the curbing **21**, the floor or foundation may be poured in a shallow excavation conforming in size and shape with the desired dimensions of the building, and the curbing **21** be formed in the usual manner by forms which can be knocked down and removed once the concrete is set. On the other hand, if the curbing and the floor are desired to be at the same level, the flooring may be poured within forms itself to raise it above the level of the supporting surface for the building whereby to provide the curb **21**. Various floor and curb constructions may be used so long as a curb having a downwardly extending edge is provided.

Providing the main supporting structure for the side walls and roof are the arch-like support members which are spaced at intervals along the depth of the building and span the width thereof. In the construction of Fig. 1, there are shown two types of arch-like floor spanning support members, the one at the front (and the one at the rear of the building not shown) comprising straight columns supporting straight members arched to join at the middle to form a rafter member. Centrally of the building of Fig. 1 there is shown an arch member having tapered columns, tapered haunch members and reverse tapered central members. This construction is shown in Fig. 2 as an intermediate member, in Fig. 14 as an end member, and will be described in more detail later. The combination in a building of stronger central members and weaker end members as in Fig. 1, comprises a modification of the invention for use when expansion is not contemplated and the combination of solely high strength rigid frame members as in the center member of Fig. 1 and end member of Fig. 14 is employed in buildings wherein expansion is contemplated or the end walls are to be open.

The untapered arch end elements as in Fig. 1 (see Fig. 3 as well) comprise relatively stright column members **23**, I-beams in cross section, and relatively straight, untapered rafter members **24**, also I-beams in cross section. Rafters **24** are fixed to the tops of columns **23** by bolts **25** penetrating the flanges on the underside of the rafter member and an extra flange **23*a*** on top of the column **11**. The outer ends of the rafter members **24** extend past the outer flanges of the columns **11** at least a distance equal to the distance which the columns are inset from the edge of the curb **10*a***. The I-beam flanges are closed at both their outer and inner ends as at **24*a*** and **24*b*** by extra flanges joining the upper and lower flanges thereof. The inner ends of the rafter members **24** abut at a ridge as shown at **26** and flanges **24*b*** are welded or bolted together there. Referring to Fig. 10, which shows the detail of the right front column at the corner in Fig. 1, it may be seen that the column **23** has a closing lower flange **23*b*** which is fixed to the concrete curb **21** or floor **20** by bolts **27**. The column is set in from both the side and front edges of the curb as shown in Fig. 10.

Referring now to Figs. 2, 4 and 14, which show the inventive tapered heavy stress column and rafter member by itself and employed in the center of the building and in the end of the building, respectively, the opposite elements of each complete arch will be numbered alike, as the construction is the same on each side. Additionally, the arches of Figs. 4 and 14 will be numbered alike in their identical elements. As in the previously described untapered arch element, the column and rafter members of the tapered element are I-beams in cross section. Vertical column **28** is tapered from a lesser depth adjacent the bottom thereof to a greater depth adjacent the top. Column **28** has horizontal plate **29** joining the I-beam flanges on the top thereof with a portion of said plate **29** extending outwardly beyond the outer flange of the column **28** a distance equal to the distance which the column is inset from the curbing edge. Gusset **30** may connect the underside of the plate extension to the column outer flange for support. Outer haunch member **31** is attachable to the top of the column at its outer end and angles upwardly inwardly toward its inner end. A portion of the lower I-beam flange of the outer haunch member **31** is angled from the line of the lower flange to form a horizontal plate **32** to match and be engaged with the horizontal column plate **29**. The web of haunch **31** extends beyond the outer edge of the column **28** to the vicinity of the outer edges of the column and haunch horizontal plates. Flange **33** at the outer end of the haunch **31** joins the haunch upper flange and the lower horizontal plate to furnish additional strength in the end of the haunch. Additional stiffeners **34** (optional) and **35** (essential) are generally added to aid in strengthening the haunch at the joint. Stiffener **35** prevents crushing or bending of the web at the critical point of stress, while **34** is extra for high load operations. Flange **33** is normal to the web of the haunch. One set of bolts (**32*a***—Fig. 4) may engage the column horizontal plate **29** and haunch horizontal plate **32** outside the outer flange of the column and another set of bolts (**32*b***—Fig. 4) may be positioned through these two plates at the inner edge of the column whereby to connect the column horizontal plate and haunch horizontal plate to form an essentially rigid joint therebetween. The column **28** web preferably increases in depth upwardly and the haunch **31** web preferably decreases in depth inwardly. Center beams **36** are tapered from a lesser depth adjacent their outer ends to a greater depth adjacent their central ends. Beams **36** are fixed to the inner ends of the haunch members **31** by horizontal plates **37** and vertical plates **37*a*** bolted to both members. The beams are bolted to one another by bolts **38** (not visible in Fig. 14, see Fig. 8) engaging the central vertical splice plates **36***a* thereof. The central flanges **36***a* preferably extend upwardly above the upper I-beam flanges of the central beams **36** as at **36***b*. Bolts **39** are fitted through these upward extensions and a flange opening **40** extends therethrough.

For any given building structure, considering dead load only, the depth of the webs in the column members, haunch members and central beams are preferably proportional to the moments therein and the joinder between the central beams and the haunch members is preferably as close to the points of inflection in the moment diagram as possible.

It should be pointed out that, so long as the depth of the web of the center beam members **36** is proportional to the bending moment therein, it does not matter whether the upper flange of the center beam members is in line with those of the haunch members or whether the lower flange thereof is positioned in any particular way relative the lower flanges of the haunch members. However, it is preferable that the upper flange of the center beam members be substantially in line with the upper flanges of the haunch members so the purlins may be of the same size (in cross section) so the roof sheets may be and lie flat. Of course, with the center beam taper, it is impossible, if the upper flanges of the center beam members are in line with the upper flanges of the haunch members, for the lower flanges of the center beam members to be in line with the upwardly inclined lower flanges of the haunch members. Therefore, preferably the lower flanges of the center beam members are essentially parallel with the floor or slightly cambered whereby to give the appearance of a flat rather than a sagging ceiling. The upper projection of the center (ridge) beam splice plates **36***b* serves as a compression joint, takes tension during the erection of the building and under wind load. The thickening of the beam downwardly also prevents this plate from extending downwardly, the width of the plate being necesary to space the bolts joining the center beams a certain distance apart.

Referring back to Figs. 1 and 3 and the general description of the building employing an untapered and frame element, a plurality of end wall posts **41** are fixed to the rafters **24** by clips **42** and are bolted at their bottoms to the floor **20**, as are the columns in Fig. 10, inset from the curb slightly. Door posts **43** are preferably **C**-shaped in cross section with their outer flanges in line with the outer edge of the curb.

Sets of diagonal brace rods **44, 45** (side), **46** and **47** (front), each provided with an intermediate turnbuckle, are provided between at least two adjacent arch elements on a side and two adjacent front posts or rear posts on the front and rear sides of the buildings for bringing these members into, and maintaining them in parallel relationship. Likewise, in the roof, a plurality of sets of tie rods (unnumbered) are provided for the same purpose relative adjacent arch elements. Figs. 10 and 8 show the manner of fixing these tie rods relative the columns and the beam members, respectively. In Fig. 8, tie rod **44** is thus fixed to the column **23** by plates **48** engaged by bolts **49**. In Fig. 8, brace rods **50** and **51** are fixed by clevises to the clip **52** of strut **53**, the whole assembly being fixed to the central beam central flanges by brace rod clip **54** by means of bolts **46**.

Girts **56** extend lengthwise of and across the ends of the building on opposite sides thereof, are preferably Z-shaped in cross section (Fig. 4) and are secured to the outer flanges of the columns and end posts **41** intermediate the upper and lower ends thereof. Sag rods **57** depend from the eave members to be described, to suspend the center section of the girts **56**. Girts **56** are secured directly to the vertical columns of the frame members, either by welding or by bolts. Fig. 11 shows the juncture of the side and end wall girts of the right

front end wall column of Fig. 1. Girt column clip **58** is affixed to the outer flange of the column by bolts **59** and the front and side girts are attached thereto by bolts **60** and **61**, respectively. Fig. 17 shows side and end girts **62** and **63** fixed relative the heavy duty end wall column by girt column clip **64** and bolts **65** and **66**, the clip itself fixed to the outer flange of the column by bolts **67**. Clip **64** has angle **68** fixed thereto to provide backing for the corner panel to be set thereagainst out to its edge.

In Figs. 1 and 3, the roof purlins **69** are also preferably Z-shaped in cross section and like the girts, span the distance between adjacent frame members. The ends of the purlins rest upon, and are secured in any suitable fashion, such as by bolts, to the upper flanges of the rafter members. Transverse sag angles **70** are utilized to connect the intermediate portions of adjacent purlins and maintain them in parallel relationship. As seen in Fig. 7, the sag angles **70** have crimped ends **71** engaging slots **72** in the purlins. The ends of the purlins **69** are attached to gable angles, to be described, by angle clips **73** (Fig. 13) bolted to the purlins at **74** and the gable angle at **75**.

As may be seen in Figs. 3, 4 and 9, the eave purlin members **76** are **C**-shaped in cross section which are secured to the outer ends of the rafters. Eave corner closures **77** (Fig. 9) carry the eave members out to the limit of the curbing and join the gable angles.

Referring to Fig. 4 particularly, flange braces **78** are employed to provide lateral support for the inside flanges of tapered arch elements employed within the building in the columns, haunch members and central beams. Braces **78** are fixed at their outer ends to the girts or purlins, respectively, and at their inner ends to the inside flanges of the various members.

Back to Fig. 1 and also looking at Fig. 12, the door jamb is formed by door posts **43**, the girts **56** on the front of the building being fixed thereto by means of clips **79** welded or otherwise attached to the inside of the door post columns. Bolts **80** connect clips **79** and girts **56**. The door posts **43** also carry at their upper ends horizontal header **81** (**U**-shaped in cross section) which is also supported by clips **81***a* (Fig. 6) connected to each of the end wall posts **41**. Stabilizing flanges **81***b* (Fig. 6) prevent rotation of posts **41** and are fixed to the front flange thereof by bolts **81***c*. Fig. 9 shows the end supports for header **81**, a clip mounted on the web of the rafter member **24**. Bolts **83** connect the clip and the header **81**. The front girts **56** are bolted to the front flanges of the end wall posts **41**. The front sag rods **57** are carried by the horizontal header **81**. The front girts and the horizontal header **81** are positioned with their edges or outer flanges essentially in line vertically with the outer edge of the curb **21** at the front.

A gable angle (**75**—Figs. 1, 13) extends outwardly from the top edge of the front and rear rafter members whereby to be in line with the curb **21** supported by the gable angle clips or plates **73** (Fig. 13) and the eave corner closures **77** (Fig. 9) which are fixed to the roof purlins **69** and the end eave members **76**, respectively. Gable angle **75** has its outer face substantially vertically in line with the outer face of the curb **21**.

The side walls of the building are formed by a plurality of corrugated rectangular panels **85** which are fastened to the framework of the building in the manner most clearly shown in Fig. 4. Each panel preferably comprises a flat metal sheet having formed therein three spaced parallel corrugations, a center corrugation and two outer corrugations which form the outer edges of the panel. An interlocking arrangement between adjacent panels is obtained by nesting the corrugations at the edges of the panel one within the other to give the appearance of a continuous single panel arrangement. The nesting corrugations may be provided with bolt apertures for the insertion of bolts to obtain a more rigid connection between panels.

As shown in Figs. 1, 3 and 4, the length of the side wall panels is preferably slightly greater than the height of the side wall of the building. The upper ends of the side wall panels are bolted to the eave members **76**, the intermediate portions are bolted to the girts **56**, and the lower ends of the side wall panels are bolted in like fashion to angle irons running around the edge of the curbing as in Fig. 10. Number **86** indicates the panel receiving angle irons, **87** the side angle iron closures, and **88** the corner closures. The angle irons **86—88** are secured on top of and along the outer edges of the curbing **21**. It will be noted, particularly from Fig. 4, that the lower ends of the corrugations are closed by flattening the ends of the corrugations against the panel sheets as at **85***a*. The same is done both above and below any windows in the building. The lower terminus of each corrugation along the length and across the width of a building is flattened or crimped in the fashion shown, thus providing a weather-tight connection with the foundation. Preferably, the panels themselves extend down to a level slightly below the angle irons **86—88** to abut with their inner faces the face of the curbing, thereby providing a complete weather-tight seal. The upper ends of the wall panels are mitered to fill the corrugations in the roof panels in weather sealing fashion.

The roof of the building is formed in much the same manner as the side walls. As is true in the side walls, the roof panels have interlocking corrugations and are disposed in interlocking side by side arrangement along the length of the building. However, each side of the roof preferably comprises three panel sections, namely, an outer eave panel **89** having a downwardly curved portion **89***a* extending beyond the side wall of the building; a flat intermediate roof panel **90** overlapping at its lower end the upper end of the eave panel; and a one-piece ridge panel **91** having angularly disposed portions extending downwardly from the ridge line of the roof on opposite sides thereof which overlap at their lower ends the upper ends of the intermediate panels. The joints provided by the interlocking corrugations lengthwise of the building and the overlapping relation between adjacent panels from the eave to the ridge line are made weather-tight by application of mastic and prevent leakage, even under the most severe conditions. The panels are secured to the framework of the building (eave members **76** and roof purlins **69**) by bolts located at suitably spaced intervals.

It should be noted that the joint formed by the intersection of the side wall panels with the eave panels is effectively shielded by the downwardly curved portion of the latter in combination with the side wall mitering. Even in strong winds, snow or rain, it is effectively deflected away from the joint and there is little or no possibility of intrusion. Also, by virtue of the single piece ridge panel, no joint is formed along the ridge line of the roof and leakage is thus impossible in this area.

It should be understood that while in Fig. 1 only a portion of the building is shown as paneled, in its completed form it is completely covered with the exception of the doors and windows. The window **92** shown in Fig. 1 has no critical construction and will not be described in detail.

In forming the end walls, side wall panels may be employed to cover the entire front of the building abutting and bolted to the horizontal header **81** at their upper ends and the outside face of the curb with the inner faces of their lower ends, the panels also being bolted to the girts at suitable intervals along their length. The header **81** is positioned at precisely the same height as the C-shaped eave member **76** whereby the same height panels may be employed around the entire building. This is a substantial advantage of the design. In forming the end walls, it is necessary to superimpose upper panel sections over the upper end of the conventional side wall panel to obtain the required height. The upper edge of the upper panel section will of course be cut along the line conforming to the pitch of the roof. The upper end panel sections communicate between and are fixed to the horizontal header **81** and the gable angle **75**. To fill the spaces over the door, pieces of the required configuration can be cut from the basic panel.

The end wall construction to support the front or rear panel sheets when a heavy duty frame member is employed, as in Fig. 14, has many similarities to, but some differences from the already described end wall construction of Figs. 1 and 3 illustrating the front door wall employing the light duty beam member.

In Fig. 14, the parts which are analogous to the showings in Figs. 1, 3 and 6–13 are numbered like the parts in these figures but are primed to distinguish them. Those parts which are not analogous to the showings in these figures are given new numbers.

Thus, referring to Fig. 14, we see end wall posts **41′**, side girts already numbered **62**, horizontal header **81′**, and sag rods **57′**. Since the rigid frame arch element shown in Fig. 14 is the same as the rigid frame arch element which is tapered in Figs. 1, 2 and 4, the parts of this member are numbered the same as in these other figures but primed as well. Additionally, the roof purlins are numbered **69** and primed analogous to the showing in Fig. 3. The eave member is numbered **76** and primed. The clips connecting the horizontal header to the end posts **41′** are numbered **81***a′* and the flange members associated therewith **81***b′*.

Referring to Fig. 18, this showing is analogous to the showing of Fig. 10, but from a different perspective. The foot of the tapered column **28′** is fixed to the floor **20′** by bolts **93**. The edge angle irons include the corner angle **94** and the side angle irons **95** which are all bolted to the curbing and in line therewith. These pieces receive the inner faces of the panel sheets in the same manner as the angle irons **86—88** of Fig. 10 do.

The mounting of the girts has already been described relative Fig. 17 with numerals **64—68**.

Referring to Fig. 16, the construction of the gable angle **75′** supports is analogous to the showing of Fig. 13 but in Fig. 16 two supporting members **73′** connect the gable angle **75′** to the purlins **69′**. These pieces are bolted to one another and the gable angle and the purlins **69′**.

Fig. 15 shows the manner of attachment of the end posts **41′** to the tapered beam **36′** (or **31′**). A plate **41***a′* is welded to a cutaway section of the top of the I-beam end posts. Plate **41***a* is engaged by an H-clip **96** which in turn is bolted to the web of the beam **36′**. This is the manner of attachment also of the end posts of Fig. 1 to the rafter member although such a detail was not shown.

In describing the assembly of the building, Figs. 2 and 8 should be referred to as the former shows the entire tapered rafter element and the latter shows the perforation in the upwardly extending plates **36***b* of the center beams. The rafter element is first completely assembled on the ground with the center beams **36** bolted to one another and their outer ends fixed by the plates **37** to the tapered haunch members **31**. A pin (not shown) is inserted through the opening **40** in the plates **36***b* and the entire assembled roof beam may be lifted as a unit by a crane or the like. Before the rafter element is lifted, the columns and end posts are erected and fixed relative one another by the girts **47**. The entire rafter unit is then lifted and placed on top of the columns to which it may be bolted. The roof purlins may then be put on and the tie rods attached on the side and end walls as well as the roof. The length of the building and the internal strength required will dictate the number of tapered rigid frame members that are required and whether such are desired as end frames. In the illustrated embodiment of Fig. 1, there are only three arch frame members in the building, only one of them (the central one) a rigid frame member. If desired, the rear frame arch could be tapered as in Fig. 14 and/or the front arch member as well.

Forces in the building

The frame itself is a rigid structure. That is, the joints at the ridge and the eave are rigid and not hinged. In the structural analysis of the building, the points of attachment of the frame to the foundation are treated as though they were hinged. This is not strictly correct, but the narrow width of the column base and the small anchor bolts offer little fixation and the concrete foundation prevents lateral movement. So, the frame is essentially a two-hinged arch. The thickness of the columns in the light duty modification of the end frame members is preferably essentially that of the bottom of the heavy duty column members. Thus, both types of the column members are treated as hinged to the same degree.

There are several forces to which a building is subjected. These are its own weight, snow load on the roof, wind load on the vertical projection of the building, etc. For the purposes of engineering analysis, these are resolved into three forces or effects; moment (or bending moment), thrust and shear. The simplest analysis of a rigid frame is that of a dead load, taking into account only the weight of the building itself. A uniformly distributed roof load such as snow merely results in a uniform increase of the various forces. However, a wind load applied to one side of the building results in eccentric loading with a positive moment in the column to which the wind is applied and a negative moment in the opposite column. In the following discussion, dead loads only will be considered.

First, considering the moments developed in the various parts of the structure (Fig. 5), since the column is presumed to be hinged at the base, it is free to rotate at this point and there is no bending moment. Moving up the column, the moment increases uniformly to the knee joint where there is a change of direction in the roof beam. This moment in the column is a negative one with the inside flange of the column under compression and the outside flange of the column under tension. The neutral axis where there is neither compression nor tension runs up the center line of the column. Since the moment varies uniformly from a maximum at the top to zero at the bottom, the column can be correspondingly designed wide at the top and narrow at the bottom. The knee joint is rigid, so the moment developed in the roof beam at this joint must equal that developed in the column and must be in the same direction. Starting at the roof beam at the knee joint where there is a maximum negative moment, in the progression up the roof beam or rafter toward the ridge, the moment decreases until it becomes zero (point of inflection) at some point between the knee and the ridge. As previously mentioned, this is preferably the point of juncture between the center beams and the tapered haunch members. It then becomes positive and remains so until the ridge is reached. The neutral axis of the roof beam lies on or near the center line. At the knee joint where the forces change direction, the neutral axis tends to pull in toward the inside flange. Although the forces flow continuously through this joint, their exact distribution depends on the type of the joint.

Thrust in the column is uniform and is directed downwardly into the foundation. The thrust in the roof beam is directed along its axis toward the knee and increases uniformly from the ridge to the knee.

The shear in the column is directed perpendicularly to the axis of the column. Since the base of the column is restrained from lateral movement by the foundation bolts, the upper part of the column tends to shear outwardly from the lower part. By convention this is called positive shear. In the column this shear is uniform. The shear in the roof beam is directed perpendicularly to the axis of the beam and varies uniformly from a positive shear at the ridge to a negative shear at the knee. At the ridge, the beam is restrained by the joints of the part of the beam away from the ridge and tends to shear downwardly from the part near the ridge. By convention this is positive. As the knee is approached, the opposite condition prevails because the part furthest from the ridge is restrained by the knee joint. Under this condition, the part of the beam farthest from the knee (nearest the ridge) tends to shear downwardly from the part nearest the knee. By convention, this shear is negative.

The forces of thrust, shear and moment in the roof beam are transmitted through the knee joint into similar but not equal forces in the column. That is to say, thrust in the roof beam does not equal thrust in the column nor does shear in the roof beam equal shear in the column. As stated previously, the moment of the column at the knee joint equals the moment at the roof beam at the same joint.

When the means which join the column and haunch horizontal plates together are in part positioned in the portions of the assembly projection beyond the outside of the column flange and in part adjacent the inside of the column, a vertical loading of the rafter tends to produce a moment so that the outermost joining means are under tension and the innermost joining means are in compression. A horizontal load on the outside face of the column or side wall of the building tends to produce a reverse moment whereby the outside joining means are under compression and the innermost joining means are under tension.

From the foregoing it will be seen that this invention is one well adapted to attain all of the ends and objects hereinabove set forth, together with other advantages which are obvious and which are inherent to the structure.

It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the claims.

As many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all material hereinabove set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

Having thus described our invention, we claim:

1. A column and rafter assembly for a low pitch rigid frame building in which the assembly provides a continuous, rigid arched frame structure for the building comprising a pair of vertical columns spaced laterally from one another and having flat, horizontal mounting surfaces at their upper ends, and an arched, unitary rafter member extending between and bridging the space between the columns and forming a ridge therebetween, said rafter member being of I construction throughout its length with upper and lower flanges defining the upper and lower flanges of the rafter member, said rafter member being symmetrical with respect to the ridge, the upper flanges on opposite sides of the ridge extending upwardly and inwardly in converging planes from the outer ends thereof to the ridge, the lower flanges at the respective outer ends being horizontal and in face to face contact with the said mounting surfaces and rigidly secured thereto whereby the beam moment due to dead load and on each side of the ridge reverses at a point intermediate the column and ridge, the lower flanges extending upwardly and inwardly from the inner edges of the columns to said reversal point at a pitch greater than the pitch of the corresponding upper flange whereby the upper

and lower flanges converge for a distance inwardly of the columns on opposite sides of the ridge, the lower flanges extending from each said reversal point to the ridge at a pitch less than the pitch of the overlying upper flange whereby the flanges diverge from the said reversal points to the ridge, and the depth of the rafter between the flanges at the ridge and adjacent thereto being sufficient as to provide the rafter member with a cross sectional moment of inertia whereby suspension of the rafter at the ridge with the ends hanging free and unsupported can be carried out without damage to the rafter member thus to render the rafter member installable on the columns by providing a single lifting force at the ridge.

2. A column and rafter assembly as in claim 1 wherein the lower flanges between the points of reversal are approximately zero pitch.

3. A column and rafter assembly as in claim 1 wherein a suspension bracket is made integral with and extends upwardly above the rafter member at the ridge to provide a suspension connection.

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