STRUCTURAL ANALYSIS OF THE INJUN V

SPACECRAFT STRUCTURE

By

Thomas C. Jones

Thesis submitted to the Graduate Faculty of the

Virginia Polytechnic Institute

in partial fulfillment for the degree of

MASTER OF SCIENCE

in

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APPROVED:

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ABSTRACT

The forces and deflections on the idealized structure of the Injun V spacecraft structure subjected to accelerations were determined through methods utilizing finite element techniques. These techniques were based on energy methods and were compiled for use in an existing structural computer program. Experimental tests were conducted to show that the structure was capable of surviving in the test acceleration environment and to obtain strains for comparison with the analytical.

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III. ACKNOWLEDGMENTS

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IV. LIST OF TABLES AND FIGURES

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V. LIST OF SYMBOLS

U	strain energy
X	displacement
F	force
k	stiffness coefficient
σ	stress
ϵ	strain
β	transformation coefficient
I	moment of inertia
K	torsional constant
A	cross-section area of beam element
t	thickness of plate element

Subscripts

i	generalized parameter
e	reference to a local coordinate system
o	reference to an overall coordinate system
m	assembled stiffness matrix referred overall coordinate system
r	system after boundary conditions have been applied
y,z	reference to local coordinate system

VI. INTRODUCTION

The solutions to structural problems using finite element techniques are, in fact, solutions to models representing structures. The mathematical solution to a model may be quite good; however, it may not be in agreement with the desired structure. For example, the development of models for structures involves assumptions associated with applied loads, joints, geometry, and joint location. It is of interest to determine the agreement which can be expected between the model of a highly redundant structure and the structure itself.

The purpose of this report is to show the correlation that exists between the mathematical representation of a model of a spacecraft structure and the solution to the actual structure obtained by experiment. It is also of interest to show that the spacecraft can survive the acceleration environment anticipated during flight. The structure upon which the study was made is the Injun V spacecraft structure. Figure 1 is a simplified schematic of the salient features of the spacecraft structure. (A sketch of the satellite in orbit is shown in figure 26.) The outer geometry of a cross section can be represented by a hexagon with maximum radius of 15 inches and an approximate length of 31 inches. This structure was designed and fabricated by the University of Iowa for the National Aeronautics and Space Administration.

The experimental solution was obtained by subjecting the spacecraft to known accelerations and measuring the strains at 11 selected points. The results of the analysis at these points are presented for comparison. An attempt will be made to resolve the discrepancies between the results of the experimental and the analytical investigations.

VII. REVIEW OF THE LITERATURE

The analysis of highly redundant elastic structures has received a great deal of attention in the last two decades (ref. 1). The rapid advancement can be attributed to two main reasons. First, the structures used in aircraft frames and spacecraft structures have become increasingly more complex. Secondly, the revolutionary development of the high-speed electronic computer has progressed to where the solution of large problems is now possible.

When considering the potential impact of modern computers, it must be recognized that the development of structural analysis, until very recently, has taken place in the context of hand-computation techniques. As a result, methods which involve extensive computation were impractical except for unusual or important problems. The other remaining avenues of approach to the solution of redundant structural problems were through the development of approximate solutions. Professor Hardy Cross presented his moment-distribution method in a paper published in 1932 (ref. 8), and Professor R. V. Southwell (ref. 9) developed his relaxation procedures during the first part of this century. These techniques were developed to obtain answers which converge on the solutions to problems which, when solved by classical means, involve large numbers of simultaneous equations.

The classical approaches to structural problems which were developed in the 19th century may be categorized into two broad groups which are commonly referred to as the stiffness and flexibility methods.

Historically, these methods have been in use for truss-type problems since Castigliano published his famous paper in 1879 entitled "Theorém de l'equilibre des systémes elastiques et ses applications" (ref. 10). More recently these concepts were adapted for matrix use on digital computers (ref. 3). The type of problems which can be solved by the stiffness approach has been broadened by extending these principles to elements describing plates. Turner, Clough, Martin, and Topp published a paper in 1956 (ref. 4) which describes a method for arriving at stiffnesses of finite triangular and rectangular elements. The overall stiffness of a surface is found by combining the stiffnesses of the individual elements describing the surface.

Both methods have the qualitites of generality and logical simplicity. In addition to possessing these qualities, they are amenable to matrix notation. Matrix notation, when applied to structures, allows a description of the problem which is compact but also allows discussion and treatment of the problem as an entity. These advantages of matrix notation applied to highly redundant structures are only realized with the use of automatic computers.

VIII. ANALYSIS

General Development

Due to the highly redundant nature of the structure, it was felt that the most convenient and practical way of handling the analysis of the spacecraft would be through the use of a structural computer program. One such existing program available for use was a program entitled "Structural Analysis and Matrix Interpretive System" (refs. 5, 6, and 7). The basis used to define the mathematical model of the structure is referred to in the literature as the Stiffness Method or the Direct Stiffness Method.

This method is based on a relationship between externally applied forces to an elastic body and the resulting deflections. The relationship is obtained from Castigliano's first theorem which states that "in any structure, the material of which is linearly or nonlinearly elastic and in which the temperature is constant and the supports are unyielding, the first partial derivative of the strain energy with respect to any particular deflection component is equal to the force applied at the point and in the direction corresponding to that deflection component" (ref. 2).

Stated mathematically,

$$\frac{\partial U}{\partial X_i} = F_i$$

where U is the strain energy of the elastic body, X_i are the generalized displacements, and F_i are the applied external forces.

Strain energy for an elastic body is obtained from the following expression:

$$U = \int_{\epsilon} \int_{v} \sigma_{ij} \, d\epsilon_{ij} \, dv$$

where σ denotes stress, ϵ denotes strain, and v denotes volume. For each element, the stress is expressed in terms of displacement corresponding to the degrees of freedom associated with the points where external forces are applied.

The partial derivative of the strain energy expression with respect to each of the generalized displacements results in a set of simultaneous equations relating the applied forces to displacements by a constant. This constant is referred to as a stiffness coefficient.

The equations can be written in the following matrix form:

$$\left\{F_e\right\} = \left[k_e\right] \left\{x_e\right\} \qquad (1)$$

where the subscript e denotes reference to a local coordinate system. The stiffness matrix $\left[k_e\right]$ is a symmetric matrix. The matrices $\left\{F_e\right\}$ and $\left\{x_e\right\}$ denote generalized forces and displacements, respectively.

The procedure for developing stiffness coefficients is followed for each element which is referenced to its own local coordinate system. Conversion to an overall coordinate system is performed by using a transformation matrix. The force is referenced to an overall coordinate system and is represented by $\left\{F_o\right\}$, and the displacement in an overall coordinate system by $\left\{x_o\right\}$. Thus,

$$\{x_e\} = [\beta]\{x_o\} \tag{2}$$

and

$$\{F_e\} = [\beta]\{F_o\} \tag{3}$$

where $[\beta]$ is a square, orthogonal matrix. Substituting equations (2) and (3) into equation (1) yields

$$[\beta]\{F_o\} = [k_e][\beta]\{x_o\}$$

$$\{F_o\} = [\beta]^{-1}[k_e][\beta]\{x_o\}$$

and

$$[\beta]^{-1} = [\beta]^T$$

therefore

$$\{F_o\} = [\beta]^T[k_e][\beta]\{x_o\}$$

and $[\beta]^T[k_e][\beta]$ can be written as $[k_o]$, the stiffness matrix for an individual element in system coordinates.

Since all components relating force to displacement for each element are referenced to a common reference system, a set of equations describing the entire structure can be assembled by summing like forces at each joint. The results are a set of simultaneous equations relating externally applied forces to displacements at each joint. Stated mathematically,

$$\left\{F_o\right\} = \left[k_m\right]\left\{x_o\right\} \tag{4}$$

where $\left\{F_o\right\}$ denotes generalized externally applied forces acting on the system, $\left[k_m\right]$ denotes the assembled master stiffness matrix, and $\left\{x_o\right\}$ denotes the generalized displacements associated with each joint.

The boundary conditions are applied to the system by eliminating rows and columns of the master stiffness matrix associated with the restraints at each joint.

Equation (4), after boundary conditions are applied, becomes

$$\left\{F_r\right\} = \left[K_r\right]\left\{x_r\right\}$$

where $\left\{F_r\right\}$ represents the forces at the joints where no restraints are imposed, $\left[K_r\right]$ represents the reduced master stiffness matrix, and $\left\{x_r\right\}$ represents the generalized joint displacements. After these displacements are solved for, they are used to determine the axial and bending strains in the structural members.

Description of the Structural Analysis and Matrix Interpretive System

The Structural Analysis and Matrix Interpretive System is a general-purpose structural computer program which was developed by the Philco Corporation under contract to the Jet Propulsion Laboratory (refs. 5, 6, and 7). The capabilities extend to cover small deflection prediction for generalized classes of structures such as trusses, frames, shells, or a combination of these structural elements.

In general, the analysis capabilities include prediction of deflection of structures under pressure, thermal, acceleration, and static loads. Also included in its capabilities is its ability to obtain resonant frequencies. A restriction concerning classes of structures is that all materials must possess a linear stress-strain relationship.

The program itself consists of a number of subroutines called pseudo-instructions designed not only for the solution of structural problems per se, but also for the performance of matrix operations such as addition, subtraction, multiplication, and inversion. The choice of which subroutine and the sequence of its use is left to the discretion of the analyst. The subroutines are divided into the generation phase and the manipulation phase. The generation phase subroutine develops stiffness matrices using information which describes the geometry of the mathematical model and the physical properties of the materials. The subroutines of the manipulation phase provide the necessary matrix operations required for the solution of the problem.

In a deflection and force analysis, such as the problem described in this paper, the program generates individual stiffness matrices for each element through one generation subroutine. All subroutines have four-letter names which indicate their function. For example, in the generation phase, BILD is the subroutine used to generate stiffness matrices. The individual stiffness matrices are combined and the problem's boundary conditions are imposed to form the stiffness matrix describing the model. This matrix is inverted and multiplied with the input load matrix to yield deflections of joints. These deflections are substituted into the matrix relationship describing element equilibrium to yield element forces. The appendix describes functions of subroutines includes the pertinent matrices and how they are manipulated to achieve the desired results.

Application to Problem

The structural problem chosen for analysis was the structure of the Injun V spacecraft. The experiment and orbit were selected to make measurements on trapped and precipitated magnetospheric particles, and magnetic and electric fields. The spacecraft will be placed in a polar orbit with perigee of 500 km and apogee of 3,500 km.

The spacecraft itself consists primarily of beams and rods, with some equipment serving as structure, in addition to performing other functions. The basic structural design is shown in figure 1. Comprising the base plate is a thrust ring, four radial beams, and six edge beams. Four columns emanate from the thrust ring and support the card cages, the balloon basket ring, and top plate. Four top-corner ties form a structural link between the top plate and the upper edges of the card cages. The top plate is further supported by outer stringers to which solar panels are attached. The top plate consists of solar pancls, six edge beams, the top ring, and other small interrelated structure. The outer edges of the base plate are supported by four bottom-corner ties. These are attached to the columns at the base of the card cages. The bases of the card cages are fixed relative to each other by two interconnected members. Figures 2 through 23 show the idealized structure. The circled numbers represent joints and are related to the coordinate system by table I. The numbers enclosed by squares represent beam elements and numbers enclosed by hexagons represent plate elements.

The loads are the result of flight accelerations acting on components and structural elements. The results of the loading condition applied to the structure during the acceleration test will be compared with the results of this analysis. The load matrix used in the analysis is shown in table II.

For this structure, geometric properties consisting of length, reference to a coordinate system, cross-sectional area, torsional constants, plate thickness, moments of inertia, and materials were used as the basic information to generate stiffness coefficients for each element referred to the element's local coordinate system. Table III summarizes geometric properties of each individual element.

IX. EXPERIMENTAL INVESTIGATION

The spacecraft was subjected to acceleration tests in a centrifuge test facility at the National Aeronautics and Space Administration, Langley Research Center. The general capability of this centrifuge facility is limited to testing a model weighing less than 2,000 pounds. The acceleration range is from 1/2g to 100g's with a maximum capacity of 50,000g pounds. These accelerations can be applied to the test specimen when the chamber is at a vacuum of 1×10^{-1} mm of mercury absolute.

As discussed previously, an objective of this test was to obtain experimental data for correlation with calculated data. Locations for strain measurements were chosen on the spacecraft's primary structural members (fig. 1). In all, 11 locations were selected with 2 gages used on members having moments. The attempt was to measure moment in one plane only. Strain-gage data were recorded continuously with angular velocity for correlation with the accelerations being applied to the spacecraft. The actual strains for each gage location were obtained by correlating current flow through the gage with deflection on the Consolidated Electrodynamics Corporation 519-A recorder.

Due to the complexities of the structure, no attempt was made to calibrate the gages by applying loads to individual members. Calibration was performed electrically, that is, an electrical resistor was placed in a parallel circuit with the strain gage on the spacecraft. The changes in resistance of the circuit are indicative of a given strain. This type calibration was performed prior to and after the acceleration was applied. The accuracy of this method of calibrating is a function of how precisely the calibrating resistance is known.

The measured strains on the spacecraft were small, which resulted in small electrical output for the gages. Amplifiers were used to increase this output to a sufficient magnitude for use with existing recording equipment.

The spacecraft was placed on the centrifuge arm oriented as shown in figure 24. This orientation in combination with an angular velocity of 20.53 rpm produces the desired acceleration vector of 3.75g in the X-direction. Due to the finite length of the centrifuge arm and the spacecraft's orientation, the acceleration varies through the spacecraft from a minimum of 3.55g to a maximum of 3.94g. During the period when the spacecraft was in motion, the test facility was evacuated to a pressure of 10 mm of mercury to reduce aerodynamic drag forces. The centrifuge was brought up to the desired angular velocity at a constant rate in 3 minutes in an effort to minimize the tangential acceleration. Once at the desired angular velocity, continuous readings were taken for 3 minutes. Upon completion of the acceleration test, the spacecraft was slowly brought to rest and the chamber pressure brought up to ambient.

X. DISCUSSION OF RESULTS

To obtain experimental results, the spacecraft was subjected to a positive acceleration of 3.75g's in the plane of rotation as shown in figure 24. These results were converted to strains by a manipulation of the net deflection indicated on the printout of the data recorder.

With the spacecraft in the stationary position shown in figure 24, the gages were adjusted to an effective zero reading, although the strains on the spacecraft's members were those induced by a 1g condition. At the angular velocity of 20.53 rpm the strain gages would be indicating strains based on an acceleration vector of 3.61g at the spacecraft's center of gravity in the radial direction as shown on figure 25. The analytically obtained strains were adjusted to vectorally eliminate the 1g condition in order to establish an equal basis for comparison of the experimentally obtained strains.

Strains on three of the members are the result of internal axial load and bending moments. In the presentation of the results shown in table IV, these members are denoted with an asterisk.

Four sources of errors in data acquisition associated with the experiment can be attributed to calibration, recorder, amplification, and printout error. The total error determined as their product is a maximum 5 percent of full-scale values for each gage. These errors are different for each gage and are listed in table V.

Strain gages were placed parallel to the geometric centerlines of each member. On the members subjected to moments as well as axial loads, two gages were used on opposite sides. This arrangement allowed axial loads and bending moments to be measured separately. Included with this desired information were extraneous torsional loads and bending moments which could not be segregated.

In general, there are two areas for errors to develop in describing the model used to analyze the spacecraft. They are associated with the geometric idealization of the spacecraft and the development of the loads.

Joints of structural elements throughout the spacecraft were considered either rigid or hinged with no provision made for the case existing between the extremes. Members which are hinged are recognized in table III by the absence of their moments of inertia and torsional constants. Errors which are attributed to this assumption are apparent when joints are examined in more detail.

The top corner ties at $\alpha = 30^{\circ}$ (member No. 340) and $\alpha = 330$ (member No. 343), and the x braces (member Nos. 269 and 271) exhibit discrepancies between experimental and calculated strains. This condition is explained by examining the calculated rotations of the joints at each end of the members. The rotations observed at these joints would create moments in a direction which would tend to bring the experimental and calculated results closer together. These members were idealized to transmit no moment which, in reality, is not entirely representative of the way these members are fastened with bolts.

The diagonal tie at $\alpha = 30^{\circ}$ (member No. 110) is a member monitored for both bending moment and axial loads. The difference between calculated strains and experimental strains is larger than any of the other members monitored. This can be explained by the additional stiffness and shift in the neutral axis the element obtains from a bundle of wires attached to the member. These geometric changes were not accounted for in the idealization.

The load matrix used to arrive at joint rotation takes into account structural weight as well as spacecraft equipment weight. Symmetry and assumed experiment rigidity were used to arrive at reactions on joints. The joint locations were idealized to represent the intersections of individual members.

Upon completion of the acceleration test, a thorough visual examination of the completely assembled and partially assembled spacecraft was made. The purpose of this examination was to determine if any member of the spacecraft had been altered. The findings of this examination indicated that the spacecraft had survived the acceleration environment in which it was tested.

It is realized that the inertial loading varied over the structure from 3.55 to 3.94g and that it was analyzed for a constant 3.75g. This variation of about 6 percent would have caused some lack of agreement but not nearly as great as that noted between the calculated and tested strains.

The actual variation of -100 percent to +82 percent between the calculated and measured strains is more likely due to the assumptions made in the mathematical model for which the program was employed. For instance, the program assumes the plate elements are attached rigidly to the bars.

Actually, the panels were attached only with rivets spaced every 6 inches. Furthermore, the joints of the bar-type members were neither penned nor fixed as assumed. Nevertheless, both sets of values are close enough together to justify use of the structure in its environment.

XI. CONCLUSIONS

The finite element, with simplifying assumptions concerning geometries and loadings, leads to strains which were only approximately the same as calculated values. The accuracy of the results could be improved if more effort is expended in using more realistic nonrigid plate and bar joints.

The visual inspection of the spacecraft upon completion of the acceleration test and a review of the strain-gage data did not reveal any areas of failure. However, the strain-gage results indicated that in testing a structure of this type with a limited number of gages, effort should be expended in more selective instrumentation. Specifically, strain gages should be grouped on fewer members in an effort to better describe the forces acting on the members.

XII. REFERENCES

1. Argyris, J. H.: On the Analysis of Complex Elastic Structures. Applied Mechanics Reviews, July 1958, pp. 331-338.
2. Norris, C. H., and Wilbus, J. B.: Elementary Structural Analysis. McGraw-Hill Book Company, Inc., 1960, pp. 8, 383-385.
3. Levy, S.: Structural Analysis and Influence Coefficients for Delta Wings. Journal of the Aeronautical Sciences, 1953, p. 449.
4. Turner, M. J., Clough, R. W., Martin, H. C., and Topp, L. J.: Journal of the Aeronautical Sciences. September 1956. pp. 805-819.
5. Lang, T. E.: Structural Analysis and Matrix Interpretive System (SAMIS) User Report. Jet Propulsion Laboratory, California Institute of Technology. Technical Memorandum No. 33-305, March 1967.
6. Melosh, R. J., and Christiansen, H. N.: Structural Analysis and Matrix Interpretive System (SAMIS) Program: Technical Report. Jet Propulsion Laboratory, California Institute of Technology. Technical Memorandum No. 33-311, November 1966.
7. Melosh, R. J., Diether, P. A., and Brennan, M.: Structural Analyses and Matrix Interpretive System (SAMIS) Program Report. Jet Propulsion Laboratory, California Institute of Technology. Technical Memorandum No. 33-307, Rev. No. 1, December 1966.
8. Cross, H.: Analysis of Continuous Frames by Distributing Fixed-End Moments. AMCE, vol. 96, 1932, p. 1.
9. Southwell, R. V.: Relaxation Methods in Engineering Sciences. Oxford University Press, 1940.

10. Castiglano, C. A. Pio: Theorém de l'equilibre des systemés elastigues et se applications. Transcribed by Ewart S. Andrews, Dover Publications, 1966.

XIII. APPENDIX

GOVERNING PSEUDO INSTRUCTIONS

This structural analysis computer program is governed by a group of instructions which has various functions. This particular force and deflection analysis was conducted essentially as listed in table VI.

Instruction No. 1.0 has the stiffness matrix (KER001) for element 1 through element 381 (KER381) generated. This is a sequential operation performed 381 times.

Instruction No. 2.0 performs the sequential addition operation 381 times, summing all element stiffness matrices and storing the resulting matrix (KZR381) on tape 9, location 382.

Instruction No. 3.0 has the combined stiffness matrix (KZR381) printed.

Instruction No. 4.0 has the load matrix (LDC001) and the structural restraints (WAE001) read in to the machine, and stored on tape 12, location 1 and tape 11, location 2, respectively.

Instruction No. 5.0 applies the restraints (WAR001) to the combined stiffness of the structure (KZR381) and stores the resulting reduced master stiffness matrix (KSR381) on tape 10, location 1.

Instruction No. 6.0 prints the reduced stiffness matrix (KSR381).

Instruction No. 7.0 inverts the reduced master stiffness matrix (KSR381) and multiplies the results by the load matrix (LDC001) to yield the deflection matrix (DFC001).

Instruction No. 8.0 has the deflection matrix (DFC001) printed.

Instruction No. 9.0 multiplies the individual stiffness matrix (KER001) by the joint deflections (DFC001) to yield the forces on the joints (FEC001).

Instruction No. 10.0 prints the force matrix (FEC001).

Instruction No. 11.0 concludes the program.

XIV. VITA

The author was born in [redacted] on [redacted] He attended a public school in Beaufort, North Carolina, and was graduated from Beaufort Grade School in June 1958. In 1962 he received the degree of Bachelor of Science in Mechanical Engineering from North Carolina State University, Raleigh, North Carolina. Upon graduation, the author was employed by the Newport News Shipbuilding and Dry Dock Company. Since December 1962 the author has been employed as an Aero-Space Technologist by the National Aeronautics and Space Administration.

TABLE I.- JOINT LOCATIONS

Joint No.	X, in.	Y, in.	Z, in.	Joint No.	X, in.	Y, in.	Z, in.
1	-4.70	-0.95	4.00	46	-4.48	0.0	22.16
4	4.48	2.58	30.98	47	-4.48	-2.58	22.16
5	4.48	-2.58	30.98	48	0.0	-4.63	22.16
7	0.0	5.30	30.98	49	4.48	2.58	22.16
8	3.88	-3.62	30.98	50	4.48	0.00	22.16
10	0.0	15.00	30.98	51	4.48	-2.58	22.16
11	-1.10	-5.18	30.98	52	-11.36	6.58	24.40
12	0.0	-15.00	30.98	53	13.00	7.50	8.70
13	13.00	-7.50	30.98	54	13.00	7.50	4.00
14	-4.48	-2.58	30.98	55	0.0	15.00	4.00
15	13.00	7.50	30.98	56	11.36	6.58	14.35
16	-4.48	2.58	30.98	57	4.48	4.63	14.35
17	-5.30	0.0	30.98	58	-4.48	6.58	24.40
18	3.40	-8.01	30.98	59	11.36	-6.58	14.35
19	-13.00	0.0	30.98	60	7.92	0.0	14.35
20	-13.00	-7.50	30.98	61	-13.00	7.50	4.00
21	-2.86	-13.34	30.98	62	4.48	2.58	14.35
22	9.89	-9.28	30.98	63	4.48	-2.58	14.35
23	8.53	-8.01	30.98	64	-11.36	-6.58	14.35
24	-13.00	7.50	30.98	65	4.48	-4.63	14.35
25	-1.72	-8.01	30.98	66	13.00	-7.50	4.00
26	-9.15	0.0	30.98	67	0.0	-15.00	4.00
27	11.36	6.58	24.40	68	-11.36	6.58	14.35
28	11.36	-6.58	24.40	69	-4.48	-4.63	14.35
29	7.92	0.0	24.40	70	-4.48	4.63	14.35
30	4.48	6.58	24.40	71	-5.16	2.98	12.20
31	4.48	2.58	24.40	72	-4.48	-2.58	14.35
32	4.48	-2.58	24.40	73	-4.48	2.58	14.35
33	4.48	-6.58	24.40	74	-13.00	-7.50	4.00
34	13.00	7.50	11.36	75	0.0	9.63	22.16
35	-4.48	2.58	24.40	76	9.60	5.54	14.35
36	-4.48	-2.58	24.40	77	-6.93	4.00	12.35
37	-11.36	-6.58	24.40	78	-6.50	11.25	4.00
38	-7.92	0.0	24.40	79	-7.92	0.0	14.35
39	0.0	15.00	11.36	80	0.0	4.63	18.26
40	-4.48	-6.58	24.40	81	11.77	6.80	4.00
41	13.00	-7.50	11.36	82	13.00	7.50	6.35
42	-13.00	7.50	11.36	83	0.0	4.93	14.35
43	-13.00	-7.50	11.36	84	9.00	9.84	4.00
44	0.0	-15.00	11.36	85	4.48	5.03	12.35
45	-4.48	2.58	22.16	86	11.77	6.80	6.35

TABLE I.- Continued

Joint No.	X, in.	Y, in.	Z, in.	Joint No.	X, in.	Y, in.	Z, in.
87	0.00	14.08	4.00	129	-9.34	-9.62	4.00
88	10.15	-5.86	4.00	130	5.41	1.00	6.35
89	11.74	-6.76	4.00	131	-7.96	-4.60	10.10
90	-13.00	4.26	4.00	132	-9.11	-5.25	4.00
91	-9.93	5.73	4.00	133	1.80	4.80	4.00
92	-6.25	3.61	12.20	134	0.0	-12.38	4.00
93	-2.30	-13.67	4.00	135	-4.48	-2.58	10.10
94	-6.93	4.00	14.35	136	-4.90	-2.83	10.10
95	6.48	-11.25	4.00	137	-9.00	-5.25	8.85
96	-11.36	4.18	14.35	138	0.0	9.55	9.75
97	13.00	-7.50	6.35	139	0.0	7.96	7.18
98	-4.48	2.58	12.20	140	-7.40	-8.50	4.00
99	0.0	-14.08	4.00	141	0.0	11.58	9.75
100	-13.00	4.26	14.35	142	0.0	12.38	14.35
101	-6.95	-4.00	11.34	143	0.0	7.63	12.25
102	-10.95	-8.67	4.00	144	0.0	11.58	13.10
103	-13.00	-1.50	4.00	145	3.78	-6.58	4.00
104	-4.48	-2.58	11.34	146	0.0	7.63	6.58
105	-10.71	-6.23	4.00	147	5.07	-8.82	7.20
106	-10.71	-6.23	6.73	148	-5.16	2.98	4.00
107	9.60	5.54	6.35	149	-9.00	-5.20	10.10
108	9.60	5.54	4.00	150	-7.80	-6.70	4.00
109	-6.93	4.00	6.00	151	-4.58	-6.86	4.00
110	8.90	0.60	4.00	152	-8.26	-4.77	4.00
111	0.0	5.90	14.35	153	0.00	0.00	0.00
112	4.48	6.15	6.00	154	-4.58	-12.38	10.86
113	8.9	0.60	6.35	155	-2.29	-9.62	4.00
114	0	12.38	4.00	157	-5.20	-5.02	4.00
115	6.48	-11.25	7.20	158	0.00	-12.35	5.48
116	6.70	8.18	4.00	159	0.0	-12.38	10.86
117	5.41	-3.12	6.35	160	-6.43	-7.96	4.00
118	0.0	11.58	7.18	161	0.0	-6.86	4.00
119	5.41	1.00	4.00	162	0.0	-9.09	4.00
120	5.41	-3.12	4.00	163	-1.28	-4.92	4.00
121	0.0	-13.10	4.00	164	-5.52	-3.19	4.00
122	-6.93	4.00	4.00	165	-4.90	-2.83	8.85
123	-4.58	-12.38	4.00	166	-4.48	-2.58	7.60
124	4.48	6.58	4.00	169	-9.00	-5.20	7.60
125	4.48	6.58	6.35	170	-6.37	-3.68	4.00
126	0.0	6.03	4.00	174	-4.90	-2.83	7.60
127	5.07	-8.82	4.00	176	3.78	-6.58	7.20

TABLE I.- Concluded

Joint No.	X, in.	Y, in.	Z, in.	Joint No.	X, in.	Y, in.	Z, in.
178	0.0	-4.63	4.00	188	0.0	-8.60	5.48
179	-7.96	-4.60	7.60	189	0.0	-8.05	7.24
180	-3.68	-6.36	4.00	192	2.41	-4.18	4.00
181	-4.58	-6.86	10.86	193	-4.48	2.58	4.00
182	-4.48	-2.58	4.00	194	0.0	4.63	4.00
183	-2.29	-9.62	10.86	195	4.48	-2.58	4.00
185	0.0	-6.86	10.86	197	4.48	2.58	4.00
187	0.0	-12.38	7.24				

TABLE II.- APPLIED LOADS

Joint No.	Force			Joint No.	Force		
	F_x, lb	F_y, lb	F_z, lb		F_x, lb	F_y, lb	F_z, lb
4	1.13			46	11.14		43.0
5	0.604			47	11.32		43.0
7	1.101			48	33.5		
8	0.768			49	11.32		-43.0
10	3.95			50	11.14		-43.0
11	1.015			51	11.32		-43.0
12	3.17			52	2.72		
13	11.073			54	2.91		
14	0.76			55	2.53		
15	11.64			56	3.023		
16	1.22			57	3.61		
17	0.333			58	2.533		
18	5.79			59	3.023		
19	3.655			60	12.09		
20	3.37			61	9.79		
21	0.81			62	0.607		
22	0.782			63	0.607		
23	0.094			64	2.53		
24	6.17			65	3.35		
25	0.096			66	2.84	-0.34	
26	6.87			67	2.00	3.00	
27	3.023			68	7.72		
28	3.023			69	2.72		
29	11.25			70	2.72		
30	3.023			71	2.73	-3.00	
31	0.155			72	0.67		
32	0.155			73	0.621		
33	3.023			74	2.49		
34	4.01			75	33.5		
35	0.155			76	3.00	-1.625	
36	0.155			77	2.72	1.625	
37	2.53			78	0.765	-0.41	
38	9.86			79	9.86		
39	4.01			80	10.147		
40	2.53			81	2.086		
41	4.01			84	0.863		
42	4.01			85	2.32	1.625	
43	4.01			87	0.172		
44	4.01			88	0.607		
45	11.32		43.0	89	2.09		

TABLE II.- Concluded

Joint No.	Force			Joint No.	Force		
	F_x, lb	F_y, lb	F_z, lb		F_x, lb	F_y, lb	F_z, lb
90	2.32	-1.625		139	0.815		
91	6.02	2.85		140	0.133		
93	0.213			141	0.815		
94	0.263			142	2.52		
95	0.76			143	2.52		
100	2.32	-1.625		145	0.108	-0.0479	
102	0.326			146	2.52		
103	5.723			147	0.716	0.0479	
105	1.667			148	3.09	-2.85	
108	3.08	-1.625		149	1.145	0.896	
109	2.72	2.00		150	4.466		
110	19.1			151	0.467		
111	0.172			152	0.152		
112	2.00	2.00		155	7.67		
113	19.1			157	4.466		
114	3.36			158	2.78		
115	0.108	-0.048		159	0.188		
116	0.196			160	0.133		
118	0.815			162	1.636		
120	1.972			164	0.109		
122	0.455			169	1.145	0.896	
123	0.672			170	1.601		
124	0.742			174	1.97	-0.896	
126	1.981			176	0.089		
127	0.716	0.048		180	0.155		
129	0.199			183	7.67		
132	0.143			185	0.188		
134	1.636			187	2.48		
136	1.97	-0.896		188	3.30		
138	0.815			189	3.30		

TABLE III.- GEOMETRIC PROPERTIES

Element no.	Joint no. describing element position	t, in.	A, in^2	K, $\times 10^{-4}$ in^4	I_{Y-Y} $\times 10^{-2}$ in^4	I_{Z-Z} $\times 10^{-2}$ in^4	Material
1	15, 10, 16		0.119	1.81	2.76	1.46	6061-T6 AL
2	13, 15, 16		.119	1.81	2.76	1.46	
3	22, 13, 16		.119	1.81	2.76	1.46	
4	12, 22, 16		.119	1.81	2.76	1.46	
5	21, 12, 16		.119	1.81	2.76	1.46	
6	20, 21, 16		.119	1.81	2.76	1.46	
7	19, 20, 16		.119	1.81	2.76	1.46	
8	24, 19, 16		.119	1.81	2.76	1.46	
9	10, 24, 16		.135	4.5	.99	.175	
10	16, 7, 10		.135	4.5	.99	.175	
11	7, 4, 10		.135	4.5	.99	.175	
12	5, 4, 10		.135	4.5	.99	.175	
13	8, 5, 10		.135	4.5	.99	.175	
14	11, 8, 10		.135	4.5	.99	.175	
15	14, 11, 10		.135	4.5	.99	.175	
16	17, 14, 10		.135	4.5	.99	.175	
17	16, 17, 10		.135	4.5	.99	.175	6061-T6 AL
18	25, 18, 10		.785	980	4.9	4.9	ALINCO-V ST
19	18, 23, 10		.785	980	4.9	4.9	ALINCO-V ST
20	23, 22, 10		.061	1.59	.206	.0245	6061-T6 AL
21	8, 23, 10		.061	1.59	.206	.0245	6061-T6 AL
22	25, 11, 10		.061	1.59	.206	.0245	6061-T6 AL
23	21, 25, 10		.061	1.59	.206	.0245	6061-T6 AL
24	26, 17, 10		.785	980	4.9	4.9	ALINCO-V ST
25	19, 26, 10		.785	980	4.9	4.9	ALINCO-V ST
26	7, 10, 16	0.010					6061-T6 AL
27	15, 10, 7	.010					6061-T6 AL
28	15, 7, 4	.010					6061-T6 AL
29	15, 4, 13	.010					6061-T6 AL

TABLE III.- Continued

Element no.	Joint no. describing element position	t, in.	A, in^2	K, $\times 10^{-4}$ in^4	I_{Y-Y} $\times 10^{-2}$ in^4	I_{Z-Z} $\times 10^{-2}$ in^4	Material
30	13, 4, 5	0.010					6061-T6 AL
31	13, 5, 22	.010					
32	22, 5, 8	.010					
33	22, 8, 12	.010					
34	12, 8, 11	.010					
35	12, 11, 21	.010					
36	21, 11, 20	.010					
37	21, 11, 14	.010					
38	20, 14, 19	.010					
39	14, 17, 19	.010					
40	17, 16, 19	.010					
41	16, 24, 19	.010					
42	10, 24, 16	.010					
43	24, 42, 193		0.063	0.846	0.22	0.0616	
44	42, 61, 193		.063	0.846	.22	.0616	
45	36, 14, 54		.0267	1.23	.00612	.00612	
46	47, 36, 54		.111	19.7	.098	.098	
47	92, 61, 193		.063	5.5	.0326	.0326	
48	73, 92, 193		.063	5.5	.0326	.0326	
49	71, 92, 193		.075	6.58	.039	.056	
50	98, 71, 193		.075	6.58	.039	.056	
51	98, 73, 68		.111	19.7	.098	.098	
52	193, 98, 68		.111	19.7	.098	.098	
53	32, 5, 16		.0276	1.23	.00612	.00612	
54	51, 32, 16		.111	19.7	.098	.098	
55	63, 51, 16		.111	19.7	.098	.098	
56	195, 63, 16		.111	19.7	.098	.098	
57	63, 66, 16		.063	5.5	.0326	.0326	
58	72, 47, 54		.111	19.7	.098	.098	6061-T6 AL

TABLE III.- Continued

Element no.	Joint no. describing element position	t, in.	A, in^2	K, $\times 10^{-4}$ in^4	I_{Y-Y} $\times 10^{-2}$ in^4	I_{Z-Z} $\times 10^{-2}$ in^4	Material
59	43, 20, 54		0.063	0.846	0.22	0.0616	6061-T6 AL
60	41, 13, 16		.063	.846	.22	.0616	
61	66, 41, 61		.063	.846	.22	.0616	
62	73, 45, 61		.111	19.7	.098	.098	
63	45, 35, 61		.111	19.7	.098	.098	
64	35, 16, 61		.0276	1.23	.00612	.00612	6061-T6 AL
65	59, 60, 56	0.115					AZ31B MG
66	59, 63, 60	.115					
67	59, 65, 63	.115					
68	63, 65, 33	.115					
69	63, 33, 51	.115					
70	63, 51, 49	.115					
71	63, 49, 62	.115					
72	63, 62, 60	.115					
73	62, 76, 60	.115					
74	60, 76, 56	.115					
75	57, 76, 62	.115					
76	56, 76, 57	.115					
77	30, 56, 57	.096					
78	27, 56, 30	.096					
79	62, 30, 57	.115					
80	62, 49, 30	.115					
81	49, 31, 30	.115					
82	49, 50, 31	.115					
83	31, 50, 32	.115					
84	32, 50, 51	.115					
85	32, 51, 33	.115					AZ31B MG
86	74, 43, 54		.063	.846	.22	.0616	6061-T6 AL
87	74, 106, 54		.062	5.5	.0326	.0326	6061-T6 AL
88	106, 137, 54		.062	5.5	.0326	.0326	6061-T6 AL

TABLE III.- Continued

Element no.	Joint no. describing element position	t, in.	A, in^2	K, $\times 10^{-4}$ in^4	I_{Y-Y} $\times 10^{-2}$ in^4	I_{Z-Z} $\times 10^{-2}$ in^4	Material
89	169, 137, 54		0.025	0.57	0.013	0.002	6061-T6 AL
90	137, 149, 54		.025	.57	.013	.002	
91	137, 131, 54		.062	5.5	.0326	.0326	
92	149, 131, 54		.025	.57	.013	.002	
93	131, 101, 54		.062	5.5	.0326	.0326	
94	131, 136, 54		.025	.57	.013	.002	
95	136, 135, 54		.02	.57	.013	.002	
96	135, 104, 54		.111	.197	.098	.098	
97	104, 72, 54		.111	.197	.098	.098	
98	101, 72, 54		.062	5.5	.0326	.0326	
99	166, 135, 54		.111	.197	.098	.098	
100	165, 136, 54		.025	.57	.013	.002	
101	174, 165, 54		.025	.57	.013	.002	
102	174, 166, 54		.025	.57	.013	.002	
103	179, 174, 54		.025	.57	.013	.002	
104	169, 179, 54		.025	.57	.013	.002	
105	182, 166, 54		.111	.197	.098	.098	
106	31, 4, 54		.0276	1.23	.00612	.00612	
107	49, 31, 54		.111	.197	.098	.098	
108	62, 49, 54		.111	.197	.098	.098	
109	197, 62, 54		.111	.197	.098	.098	
110	62, 86, 54		.062	5.5	.0326	.0326	
111	81, 86, 81		.162	.252	.0846	.571	
112	53, 82, 81		.063	.846	.22	.0616	
113	34, 53, 81		.063	.846	.22	.0616	
114	15, 34, 54		.063	.846	.22	.0616	
115	86, 82, 54		.189	.39	.0985	.895	
116	34, 15, 13	0.01					
117	39, 10, 15	.01					6061-T6 AL

TABLE III.- Continued

Element no.	Joint no. describing element position	t, in.	A, in^2	K, $\times 10^{-4}$ in^4	I_{Y-Y} $\times 10^{-2}$ in^4	I_{Z-Z} $\times 10^{-2}$ in^4	Material
118	42, 24, 10	0.01					6061-T6 AL
119	43, 20, 24	.01					
120	44, 12, 20	.01					
121	41, 13, 12	.01					
122	34, 13, 41	.01					
123	39, 15, 34	.01					
124	42, 10, 39	.01					
125	43, 24, 42	.01					
126	44, 20, 43	.01					
127	41, 12, 44	.01					
128	54, 34, 41	.01					
129	55, 39, 34	.01					
130	61, 42, 39	.01					
131	74, 43, 42	.01					
132	67, 44, 43	.01					
133	66, 41, 44	.01					
134	54, 41, 66	.01					
135	55, 34, 54	.01					
136	61, 39, 55	.01					
137	74, 42, 61	.01					
138	67, 43, 74	.01					
139	66, 44, 67	.01					6061-T6 AL
140	33, 65, 59	.096					AZ31B MG
141	59, 28, 33	.096					
142	59, 27, 28	.115					
143	59, 56, 27	.115					
144	28, 32, 33	.115					
145	28, 29, 32	.115					
146	31, 29, 27	.115					AZ31B MG

TABLE III.- Continued

Element no.	Joint no. describing element position	t, in.	A, in^2	K, $\times 10^{-4}$ in^4	I_{Y-Y} $\times 10^{-2}$ in^4	I_{Z-Z} $\times 10^{-2}$ in^4	Material
147	31, 27, 30	0.115					AZ31B MG
148	29, 28, 27	.115					AZ31B MG
149	29, 31, 32	.115					AZ31B MG
150	61, 90, 55		0.147	1.9	4.59	0.294	6061-T6 AL
151	90, 103, 55		.147	1.9	4.59	.294	
152	103, 1, 55		.490	4930	30.4	30.4	
153	103, 74, 55		.147	1.9	4.59	.294	
154	74, 105, 55		.130	1.63	.983	.0283	
155	74, 102, 55		.147	1.9	4.59	.294	
156	105, 132, 55		.130	16.3	.983	.0283	
157	102, 129, 55		.147	1.9	4.59	.0294	
158	132, 152, 55		.189	39.0	.895	.0985	
159	132, 150, 140	.0625					
160	129, 140, 55		.20	32.0	1.07	.104	
161	140, 160, 50		.20	32.0	1.07	.104	
162	132, 152, 150	.0625					
163	152, 170, 55		.189	39.0	.895	.0985	
164	170, 164, 55		.189	39.0	.895	.0985	
165	164, 182, 55		.189	39.0	.895	.0985	
166	152, 160, 150	.0625					
167	160, 140, 150	.0625					
168	180, 163, 55		.20	32.0	1.02	.104	
169	151, 180, 55		.20	32.0	1.02	.104	
170	160, 151, 55		.20	32.0	1.02	.104	
171	170, 164, 157	.0625					
172	164, 180, 157	.0625					
173	180, 151, 157	.0625					
174	151, 170, 157	.0625					
175	129, 123, 55		.147	1.9	4.59	.294	6061-T6 AL

TABLE III.- Continued

Element no.	Joint no. describing element position	t, in.	A, in^2	K, $\times 10^{-4}$ in^4	I_{Y-Y} $\times 10^{-2}$ in^4	I_{Z-Z} $\times 10^{-2}$ in^4	Material
176	151, 155, 123	0.04					AZ31B MG
177	151, 161, 155	.04					AZ31B MG
178	134, 123, 155	.04					AZ31B MG
179	161, 134, 155	.04					AZ31B MG
180	123, 93, 55		0.147	1.9	4.59	0.294	6061-T6 AL
181	93, 67, 55		.147	1.9	4.59	.294	
182	67, 99, 90		.125	17.9	.265	.0651	
183	99, 121, 90		.125	17.9	.265	.0651	
184	121, 134, 90		.125	17.9	.265	.0651	
185	134, 162, 90		.125	17.9	.265	.0651	
186	162, 161, 90		.125	17.9	.265	.0651	
187	161, 178, 90		.125	17.9	.265	.0651	
188	67, 95, 55		.147	1.9	4.59	.294	
189	127, 95, 55		.073	.9	.325	.205	
190	145, 127, 55		.073	.9	.325	.205	
191	192, 145, 55		.073	.9	.325	.205	
192	95, 66, 55		.147	1.9	4.59	.294	
193	89, 66, 55		.13	16.3	.983	.0283	
194	88, 89, 55		.13	16.3	.983	.0283	
195	120, 88, 55		.13	16.3	.983	.0283	
196	195, 120, 55		.189	39.0	.895	.0985	
197	66, 54, 55		.147	1.9	4.59	.294	
198	54, 84, 90		.147	1.9	4.59	.294	
199	81, 54, 55		.189	39.0	.895	.0985	
200	108, 81, 55		.13	1.63	.983	.0283	
201	197, 108, 55		.13	1.63	.983	.104	
202	133, 124, 55		.2	32.0	1.07	.104	
203	124, 116, 55		.2	32.0	1.07	.104	
204	116, 84, 55		.2	32.0	1.07	.104	6061-T6 AL

TABLE III.- Continued

Element no.	Joint no. describing element position	t, in.	A, in^2	K, $\times 10^{-4}$ in^4	I_{Y-Y} $\times 10^{-2}$ in^4	I_{Z-Z} $\times 10^{-2}$ in^4	Material
205	84, 55, 90		0.147	1.9	4.59	0.294	6061-T6 AL
206	87, 55, 90		.078	12.2	.146	.0443	
207	114, 87, 90		.078	12.2	.146	.0443	
208	126, 114, 90		.078	12.2	.146	.0443	
209	194, 126, 90		.078	12.2	.146	.0443	
210	55, 78, 90		.147	1.9	4.59	.294	
211	78, 61, 90		.147	1.9	4.59	.294	
212	61, 91, 55		.130	16.3	.983	.0283	
213	91, 122, 55		.130	16.3	.983	.0283	
214	122, 148, 55		.130	16.3	.983	.0283	
215	148, 193, 55		.189	39.0	.895	.0985	
216	90, 122, 55		.062	.8	.14	.18	6061-T6 AL
217	69, 40, 64	0.096					AZ31B MG
218	40, 37, 64	.096					
219	40, 69, 72	.115					
220	47, 40, 72	.115					
221	47, 36, 40	.115					
222	36, 47, 46	.115					
223	36, 46, 35	.115					
224	46, 45, 35	.115					
225	35, 45, 58	.115					
226	58, 45, 73	.115					
227	58, 70, 73	.115					
228	70, 73, 94	.115					
229	70, 94, 68	.115					
230	94, 96, 68	.115					
231	94, 79, 96	.115					
232	94, 73, 79	.115					
233	79, 73, 72	.115					AZ31B MG

TABLE III.- Continued

Element no.	Joint no. describing element position	t, in.	A, in^2	K, $\times 10^{-4}$ in^4	I_{Y-Y} $\times 10^{-2}$ in^4	I_{Z-Z} $\times 10^{-2}$ in^4	Material
234	73, 47, 72	0.115					AZ31B MG
235	73, 45, 47	.115					
236	72, 69, 64	.115					
237	79, 72, 64	.115					
238	79, 64, 96	.115					
239	68, 58, 70	.096					
240	68, 52, 58	.096					
241	52, 35, 58	.115					
242	52, 38, 35	.115					
243	52, 37, 38	.115					
244	38, 36, 35	.115					
245	38, 37, 36	.115					
246	37, 40, 36	.115					
247	37, 52, 68	.03					
248	37, 68, 64	.03					AZ31B MG
249	182, 123, 102	.01					6061-T6 AL
250	182, 178, 123	.01					
251	178, 93, 123	.01					
252	178, 67, 93	.01					
253	178, 95, 67	.01					
254	178, 195, 95	.01					
255	195, 66, 95	.01					
256	195, 197, 66	.01					
257	197, 54, 66	.01					
258	197, 84, 54	.01					
259	197, 194, 84	.01					
260	194, 55, 84	.01					
261	194, 73, 55	.01					
262	194, 193, 78	.01					6061-T6 AL

TABLE III.- Continued

Element no.	Joint no. describing element position	t, in.	A, in^2	K, $\times 10^{-4}$ in^4	I_{Y-Y} $\times 10^{-2}$ in^4	I_{Z-Z} $\times 10^{-2}$ in^4	Material
263	193, 61, 78	0.01					6061-T6 AL
264	193, 90, 61	.01					
265	193, 182, 90	.01					
266	182, 74, 90	.01					
267	182, 102, 74	.01					
268	197, 63, 62		0.0377				
269	182, 73, 72		.0377				
270	195, 62, 57		.0377				
271	193, 72, 69		.0377				
272	134, 158, 87		.037	0.83	0.0226	0.062	
273	158, 187, 87		.037	.83	.0226	.062	
274	187, 159, 87		.037	.83	.0226	.062	
275	159, 185, 87		.037	.83	.0226	.062	
276	189, 185, 87		.037	.83	.0226	.062	
277	188, 189, 87		.037	.83	.0226	.062	
278	162, 188, 87		.037	.83	.0226	.062	
279	126, 146, 87		.037	.83	.0226	.062	
280	146, 139, 87		.037	.83	.0226	.062	
281	139, 138, 87		.037	.83	.0226	.062	
282	138, 143, 55		.037	.83	.0226	.062	
283	143, 111, 55		.037	.83	.0226	.062	
284	111, 142, 55		.037	.83	.0226	.062	
285	144, 142, 55		.037	.83	.0226	.062	
286	138, 144, 55		.037	.83	.0226	.062	
287	118, 138, 55		.037	.83	.0226	.062	
288	141, 144, 55		.037	.83	.0226	.062	
289	118, 141, 55		.037	.83	.0226	.062	
290	87, 118, 55		.037	.83	.0226	.06	
291	192, 176, 145		.066				6061-T6 AL

TABLE III.- Continued

Element no.	Joint no. describing element position	t, in.	A, in^2	K, $\times 10^{-4}$ in^4	I_{Y-Y} $\times 10^{-2}$ in^4	I_{Z-Z} $\times 10^{-2}$ in^4	Material
292	176, 147, 145		0.075				6061-T6 AL
293	147, 115, 145		.075				↓
294	115, 95, 145		.0347				
295	145, 176, 115		.087				
296	127, 147, 115		.087				6061-T6 AL
297	154, 159, 183	0.04					AZ31B MG
298	159, 185, 183	.04					↓
299	185, 181, 183	.04					
300	181, 154, 183	.04					
301	161, 159, 134	.03					
302	161, 185, 159	.03					
303	151, 154, 181	.03					
304	151, 123, 154	.03					
305	123, 134, 154	.04					
306	134, 159, 154	.04					
307	161, 181, 185	.04					
308	161, 151, 181	.04					
309	117, 97, 113	.072					
310	113, 97, 82	.072					
311	113, 82, 107	.072					
312	113, 107, 125	.072					
313	113, 125, 130	.072					
314	113, 130, 117	.072					
315	97, 89, 81	.072					
316	81, 82, 97	.072					
317	119, 120, 117	.072					
318	119, 117, 130	.072					
319	119, 130, 125	.072					
320	119, 125, 124	.072					AZ31B MG

TABLE III.- Continued

Element no.	Joint no. describing element position	t, in.	A, in^2	K, $\times 10^{-4}$ in^4	I_{Y-Y} $\times 10^{-2}$ in^4	I_{Z-Z} $\times 10^{-2}$ in^4	Material
321	108, 124, 125	0.072					AZ31B MG
322	108, 125, 107	.072					
323	108, 107, 82	.072					
324	81, 82, 54	.072					
325	88, 66, 97	.072					
326	88, 97, 117	.072					
327	88, 117, 120	.072					AZ31B MG
328	112, 124, 108		0.062	0.80	0.18	0.14	6061-T6 AL
329	85, 112, 108		.062	.80	.18	.14	
330	76, 85, 108		.111	25.0	.0122	.43	
331	108, 76, 112		.062	.80	.18	.14	
332	108, 112, 124		.071	.99	.037	.526	
333	122, 109, 90		.062	.80	.0122	.14	
334	109, 77, 90		.062	.80	.0122	.14	
335	77, 94, 90		.062	.80	.0122	.14	
336	77, 100, 90		.14	56.0	.39	.56	
337	94, 96, 90		.062	.80	.18	.14	
338	96, 100, 90		.062	.80	.18	.14	
339	100, 90, 122		.062	.80	.18	.14	
340	109, 90, 122		.14	56.0	.396	.56	
341	27, 15, 82		.0491				
342	20, 37, 43		.0491				
343	13, 28, 41		.0491				
344	52, 24, 42		.0491				
345	57, 83, 56		.058	.75	.127	.127	
346	83, 70, 72		.058	.75	.127	.127	
347	69, 65, 64		.058	.75	.127	.127	6061-T6 AL
348	120, 119, 110	.072					AZ31B MG
349	88, 120, 110	.072					AZ31B MG
350	89, 88, 110	.072					AZ31B MG

TABLE III.- Concluded

Element no.	Joint no. describing element position	t, in.	A, in^2	K, $\times 10^{-4}$ in^4	I_{Y-Y} $\times 10^{-2}$ in^4	I_{Z-Z} $\times 10^{-2}$ in^4	Material
351	81, 89, 110	0.072					AZ31B MG
352	108, 81, 110	.072					AZ31B MG
353	124, 108, 110	.072					AZ31B MG
354	119, 124, 110	.072					AZ31B MG
355	178, 69, 83		0.0377				6061-T6 AL
356	69, 48, 83		.022				
357	48, 65, 83		.022				
358	65, 178, 83		.0377				
359	194, 57, 70		.0377				
360	57, 75, 70		.022				
361	75, 70, 57		.022				
362	70, 194, 57		.037				6061-T6 AL
363	83, 80, 70		.282	1750.0	9.9	9.9	
364	80, 75, 70		.282	1750.0	9.9	9.9	
365	76, 57, 85		.062				6061-T6 AL
366	57, 85, 76		.062				
367	83, 111, 126		.063				
368	124, 108, 76		.062				
369	67, 44, 185		.063				
370	44, 12, 185		.063				
371	39, 55, 185		.063				
372	10, 39, 185		.063				
373	45, 75, 48		.204	.82	2.01	1.73	
374	51, 48, 75		.204	.82	2.01	1.73	
375	75, 49, 48		.204	.82	2.01	1.73	
376	48, 47, 75		.204	.82	2.01	1.73	
377	47, 46, 75		.204	.82	2.01	1.73	
378	49, 50, 75		.204	.82	2.01	1.73	
379	46, 45, 75		.204	.82	2.01	1.73	
380	50, 51, 75		.204	.82	2.01	1.73	6061-T6 AL
381	108, 82, 81	.072					AZ31B MG

TABLE IV.- CALCULATED AND EXPERIMENTALLY OBTAINED STRAINS

Member number and description	Calculated strain, μin./in.	Experimental strain, μin./in.
341, top corner tie, $\alpha = 30^{\circ}$	-50.3	-90.2
343, top corner tie, $\alpha = 330^{\circ}$	-61.8	-112.1
360, upper "V," first quadrant	-124.4	-135.0
357, upper "V," fourth quadrant	-174.6	-149.8
359, lower "V," first quadrant	+158.9	+191.5
358, lower "V," fourth quadrant	+159.6	+244.6
271, "X" brace	+67.0	+46.2
269, "X" brace	+65.4	+34.2
56*, pillars, $\alpha = 30^{\circ}$, inward radial side	-141.6	-280.3
56*, pillar, $\alpha = 30^{\circ}$, outer radial side	-84.7	-144.3
110*, lower corner tie, $\alpha = 30^{\circ}$, bottom side	-148.4	-223.2
110*, lower corner tie, $\alpha = 30^{\circ}$, top side	-76.6	-18.6
193*, base radial beam, $\alpha = 30^{\circ}$, top side	+174.2	+258.2
193*, base radial beam, $\alpha = 30^{\circ}$, bottom side	-114.3	-206.8

*Denotes members having bending and axial loads.

TABLE V.- INSTRUMENTATION ERRORS

Member number and description	Maximum expected error, μin./in.
341, top corner tie, $\alpha = 30^{\circ}$	12
343, top corner tie, $\alpha = 330^{\circ}$	13
360, upper "V," first quadrant	19
357, upper "V," fourth quadrant	26
359, lower "V," first quadrant	22
358, lower "V," fourth quadrant	31
271, "X" brace	25
269, "X" brace	17
56*, pillars, $\alpha = 30^{\circ}$, inward radial side	16
110*, lower corner tie, $\alpha = 30^{\circ}$, bottom side	18
110*, lower corner tie, $\alpha = 30^{\circ}$, bottom side	14
193*, base radial beam, $\alpha = 30^{\circ}$, top side	24
193*, base radial beam, $\alpha = 30^{\circ}$, bottom side	23

TABLE VI

Instruction number	Matrix A		Matrix B		Pseudo instruction	Matrix C		Number of sequential operations
	Tape number and location	Matrix name	Tape number and location	Matrix name		Tape number and location	Matrix name	
1.0	9001	KER001			BILD			381
2.0	9001	KER001			ADDS	9382	KZR381	381
3.0			9382	KZR381	INKS			
4.0	12001	LDC001	11002	WAR001	READ			
5.0	11002	WAR001	9382	KZR381	WASH	10001	KSR381	
6.0			10001	KSR381	INKS			
7.0	10001	KSR381	12001	LDC001	CHOL	11003	DFC001	
8.0			11003	DFC001	INKS			
9.0	9001	KER001	11003	DFC001	MULT	11004	FEC001	381
10.0			11004	FEC001	INKS			381
11.0					HALT			

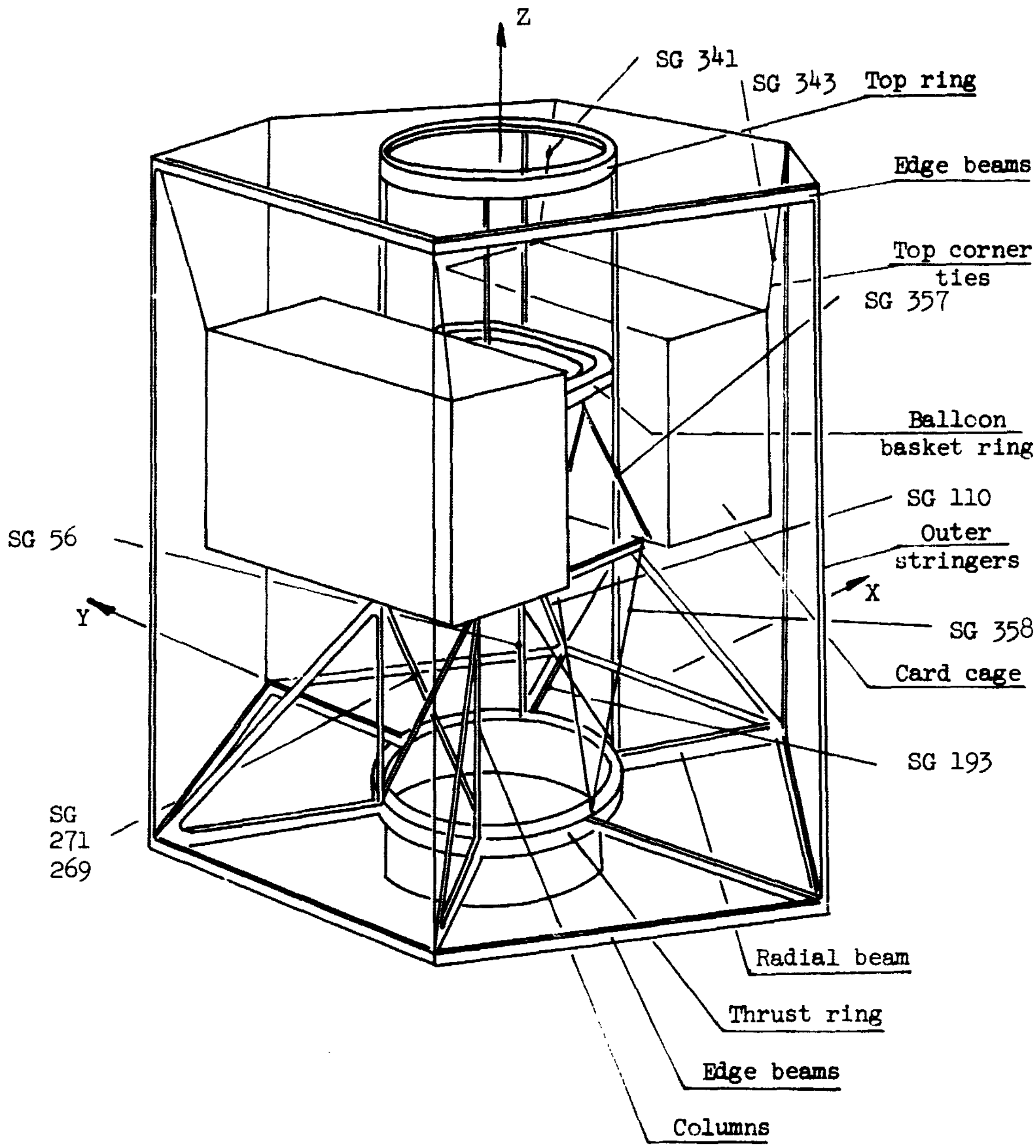

Figure 1.- Basic structure.

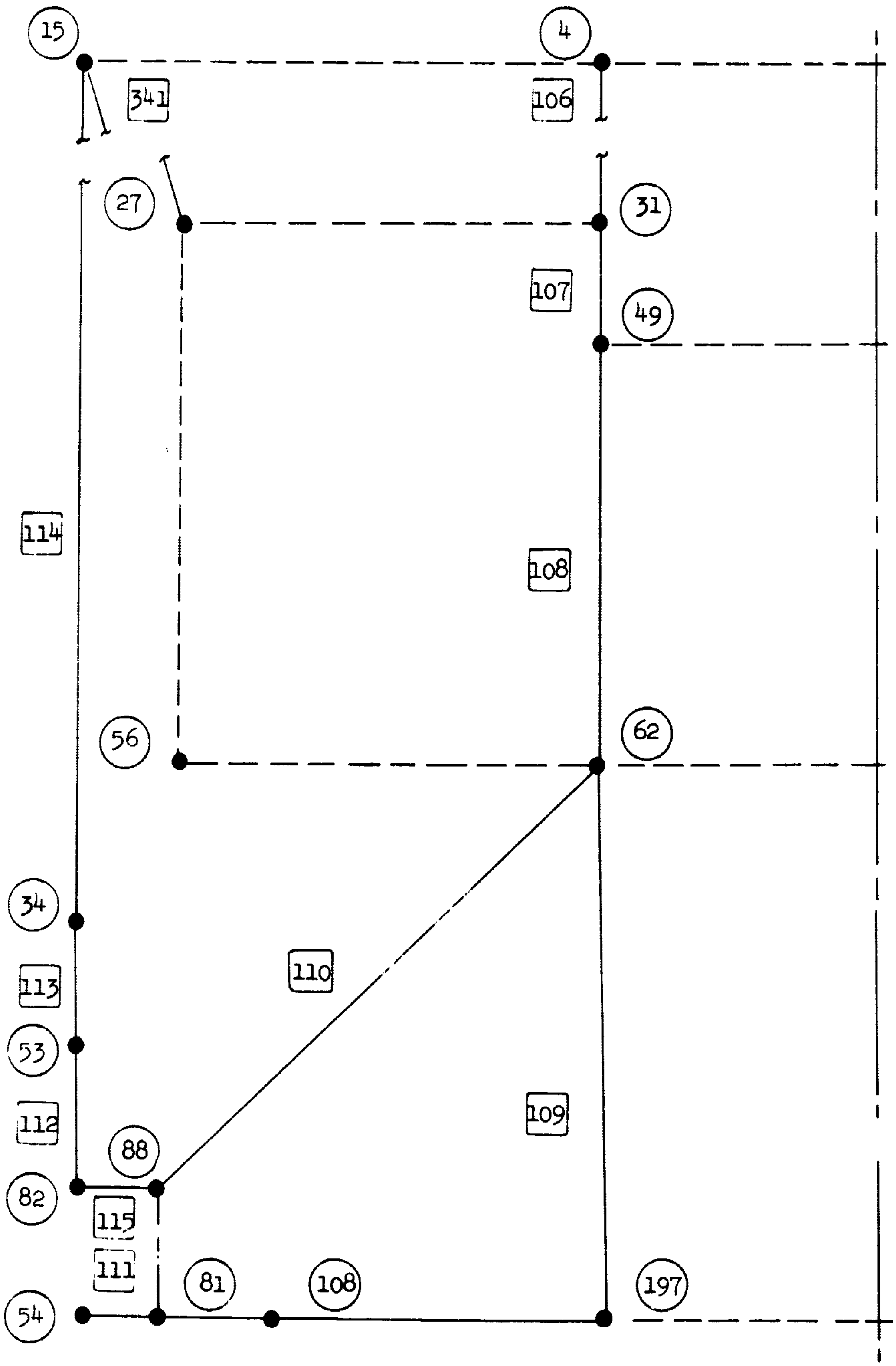

Figure 2.- Idealized structure, $\alpha = 30^{\circ}$, vertical members.

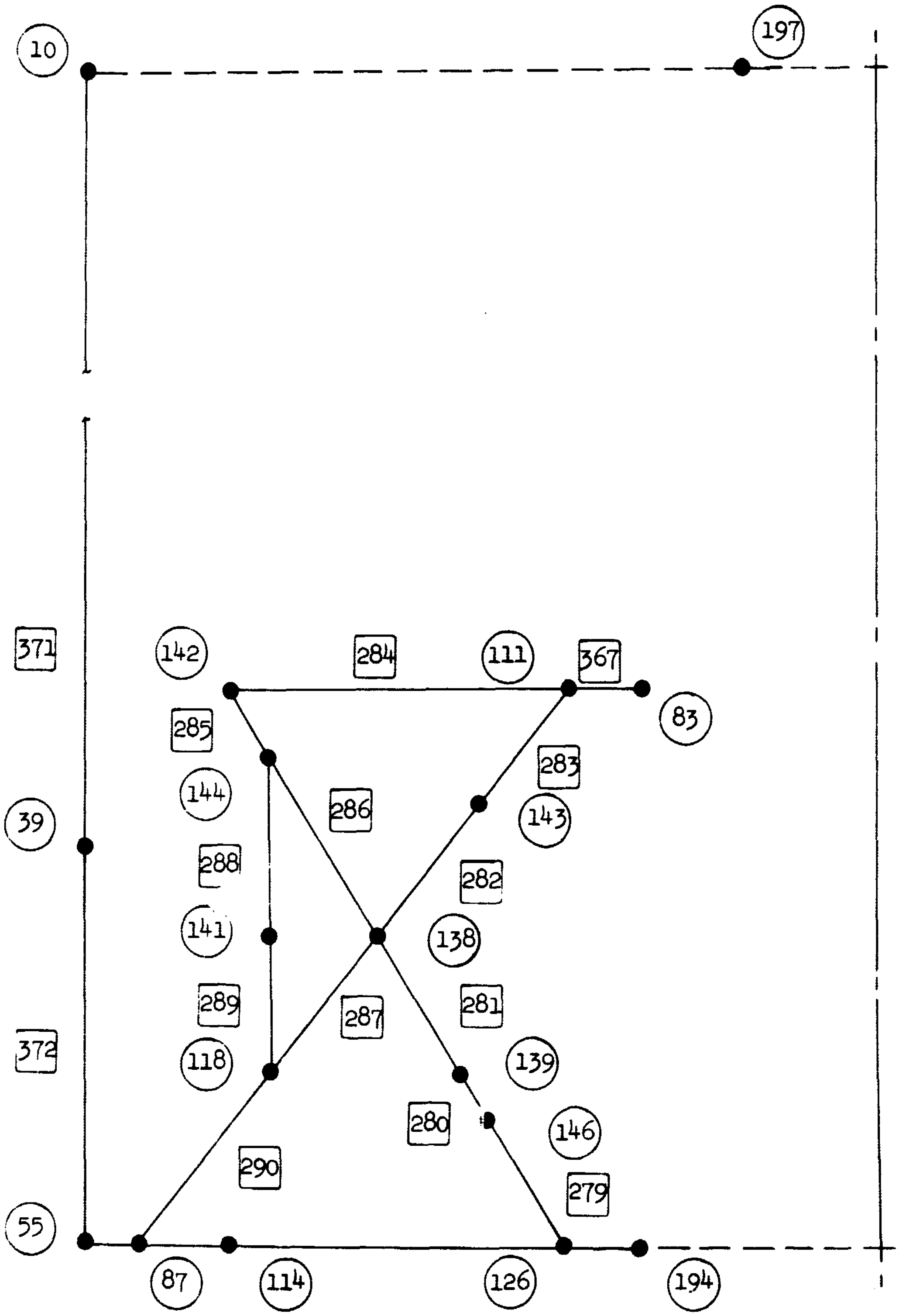

Figure 3.- Idealized structure, $\alpha = 90^\circ$, vertical members.

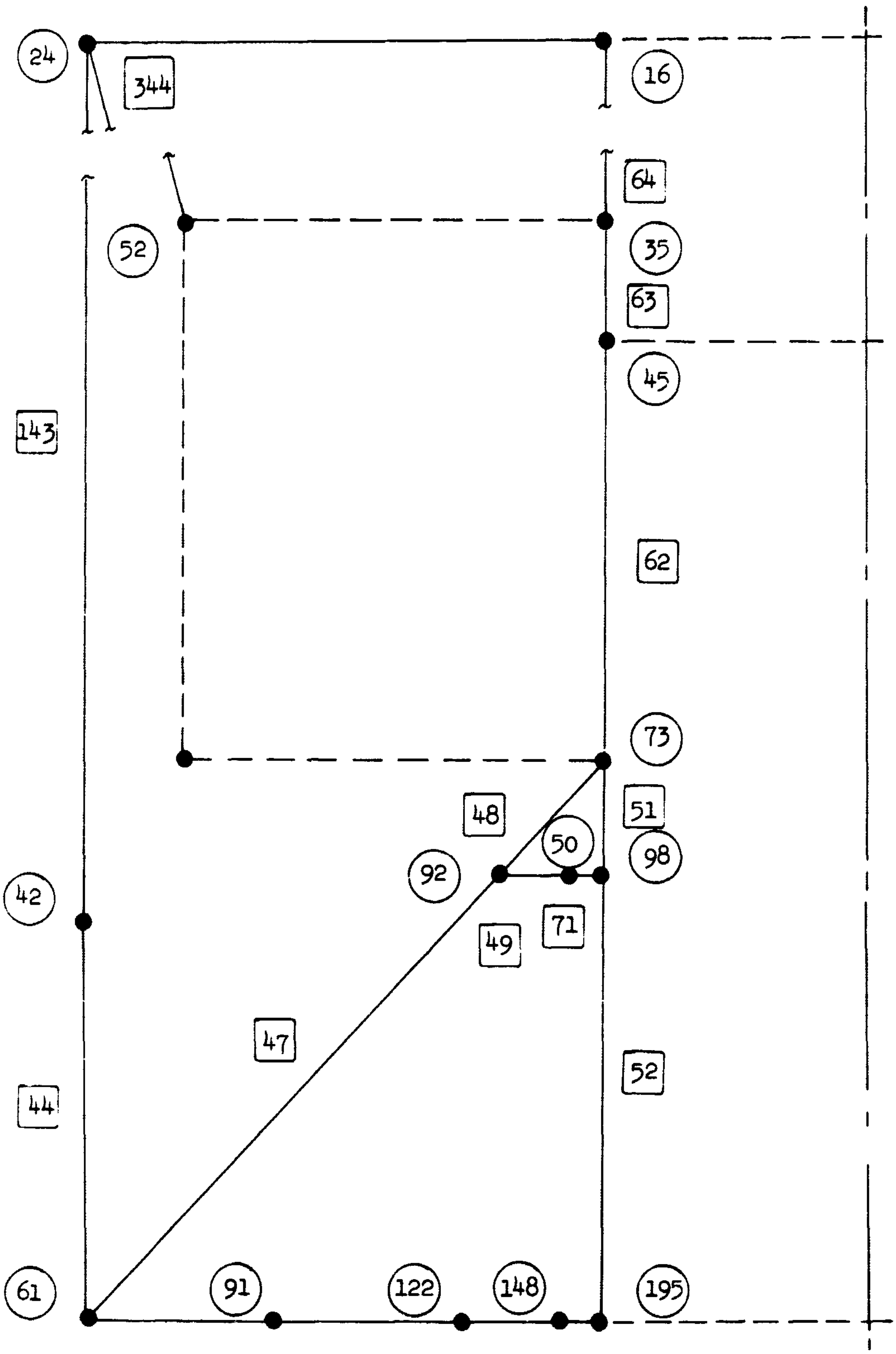

Figure 4.- Idealized structure, $\alpha = 150^{\circ}$, vertical members

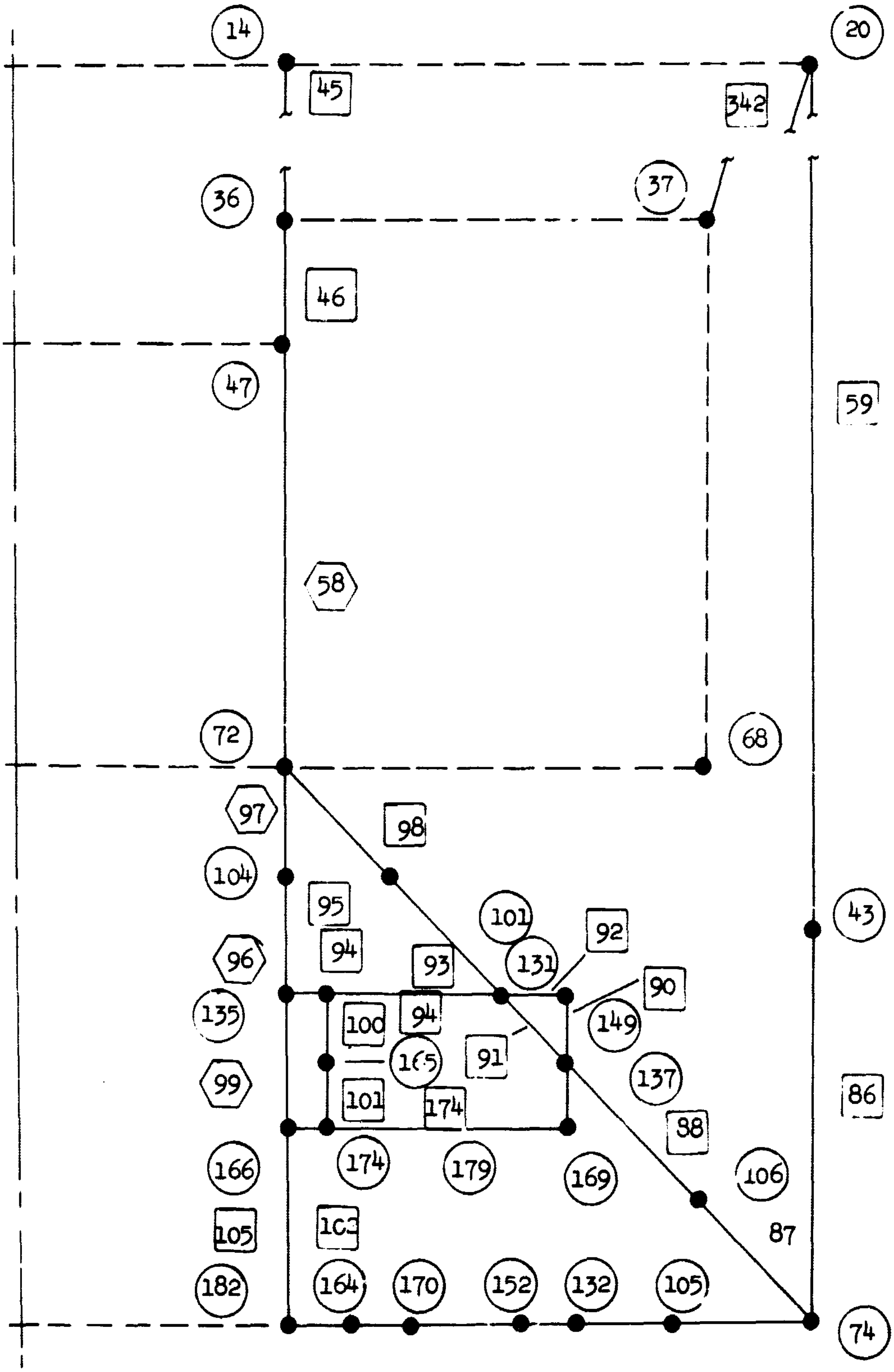

Figure 5.- Idealized structure, $\alpha = 210^{\circ}$, vertical members

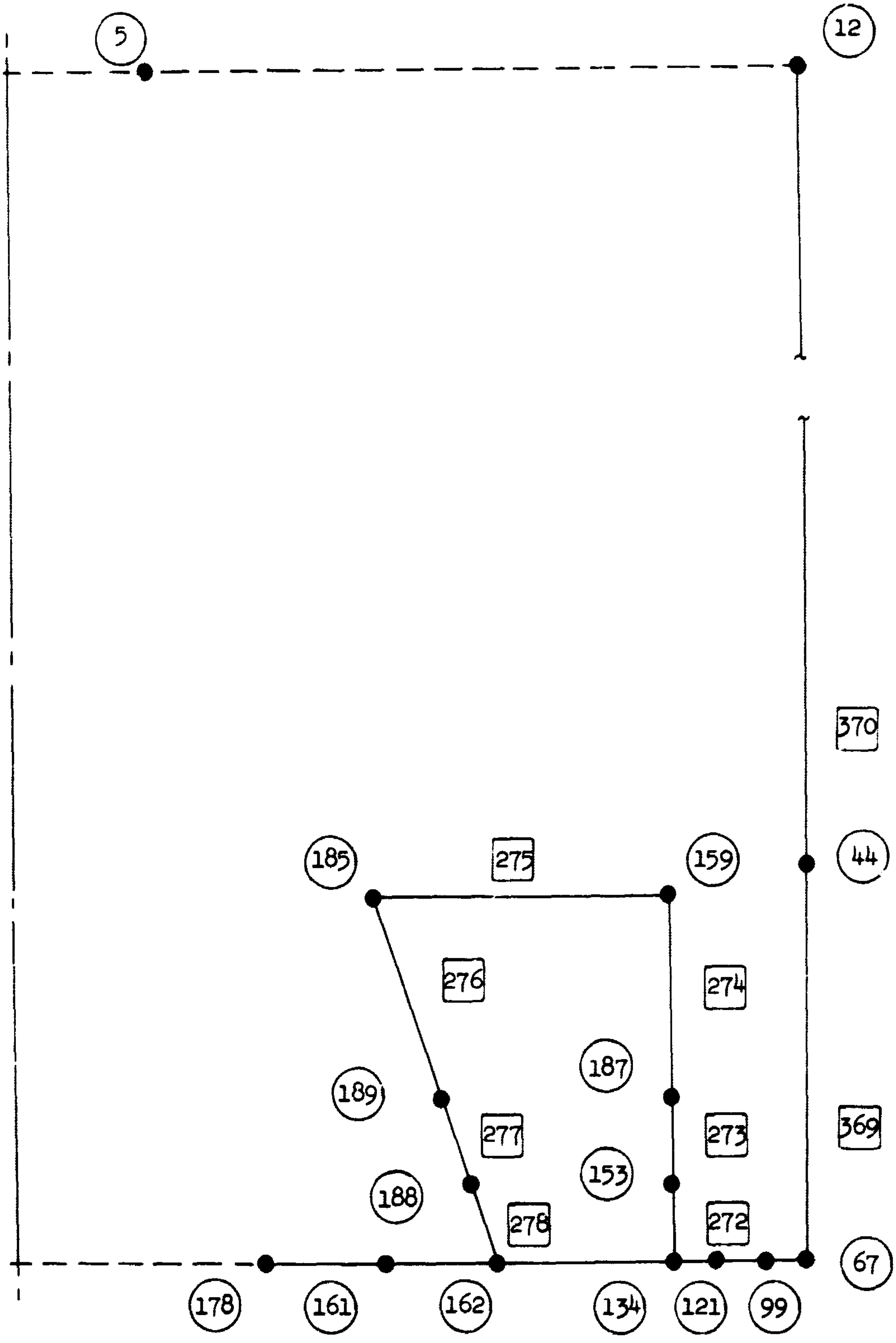

Figure 6.- Idealized structure, α = 270, vertical members.

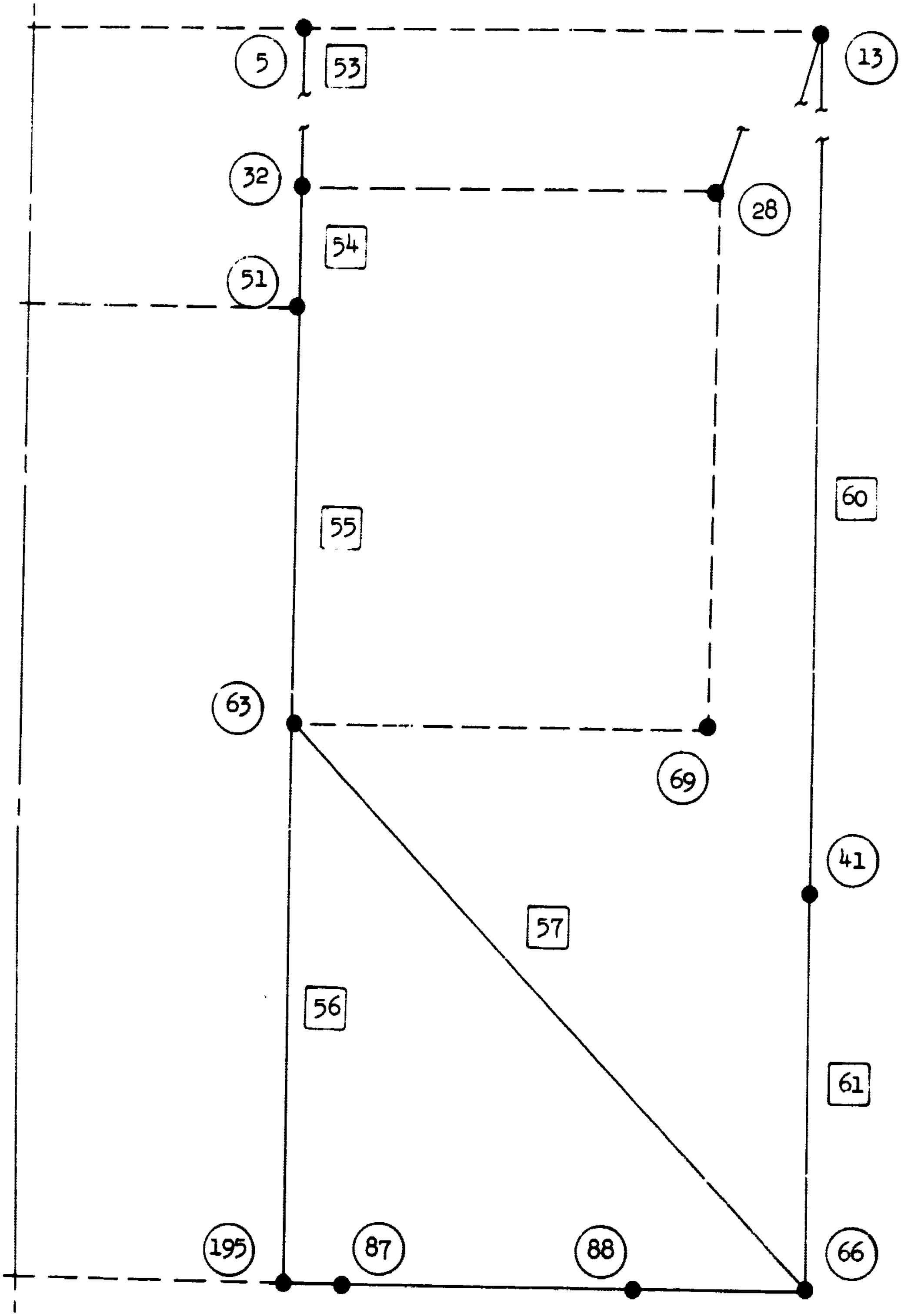

Figure 7.- Idealized structure, $\alpha = 330^{\circ}$, vertical member.

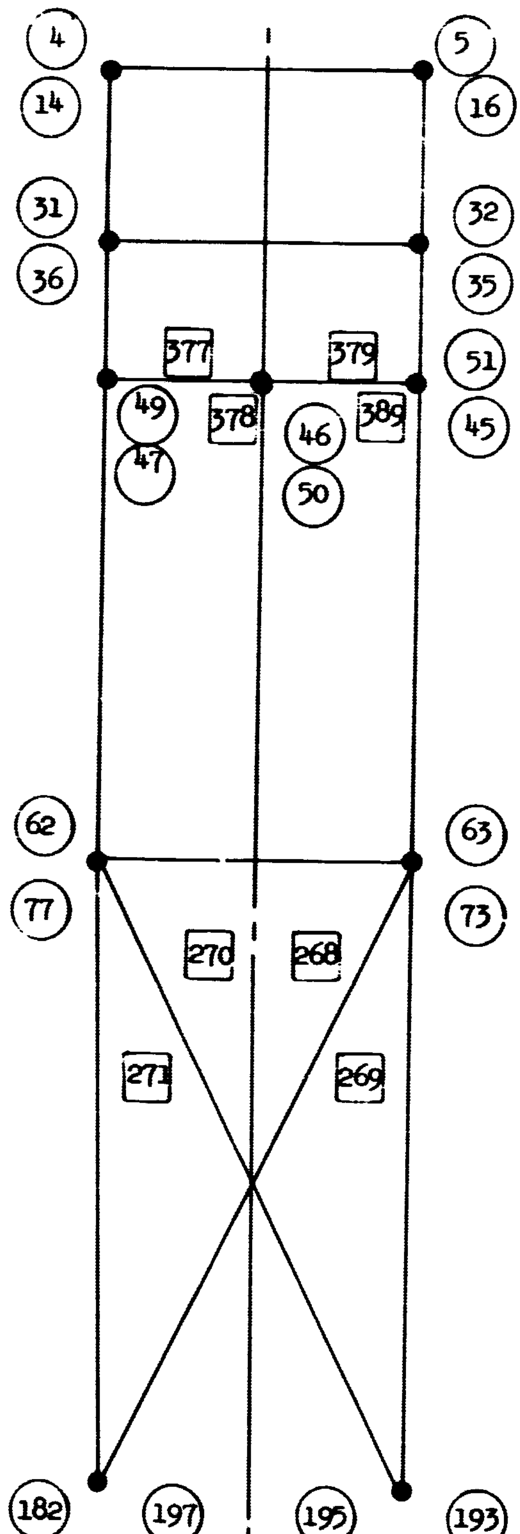

Figure 8.- Idealized structure, "x" braces.

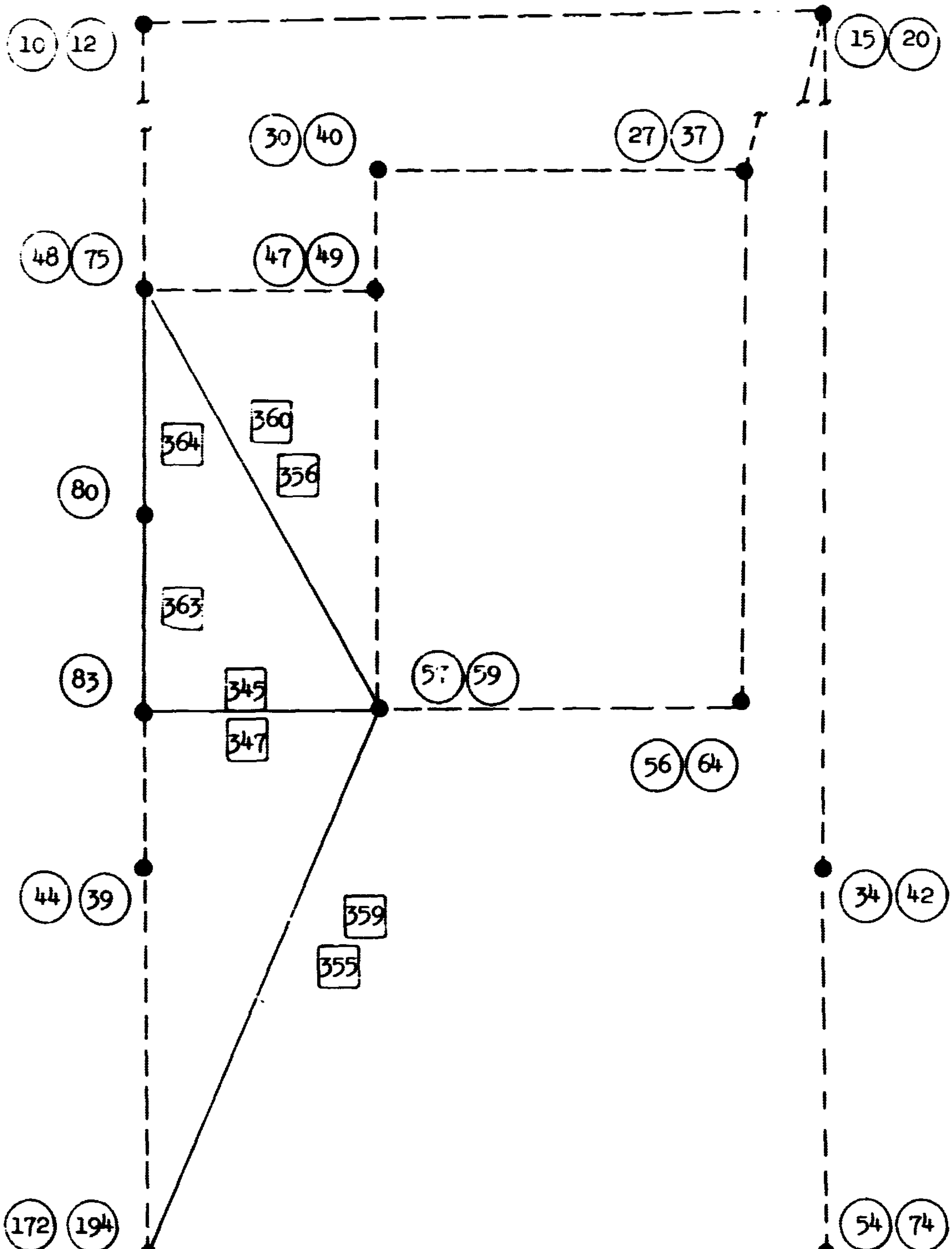

Figure 9.- Idealized structure, diagonal ties, first and third quadrant.

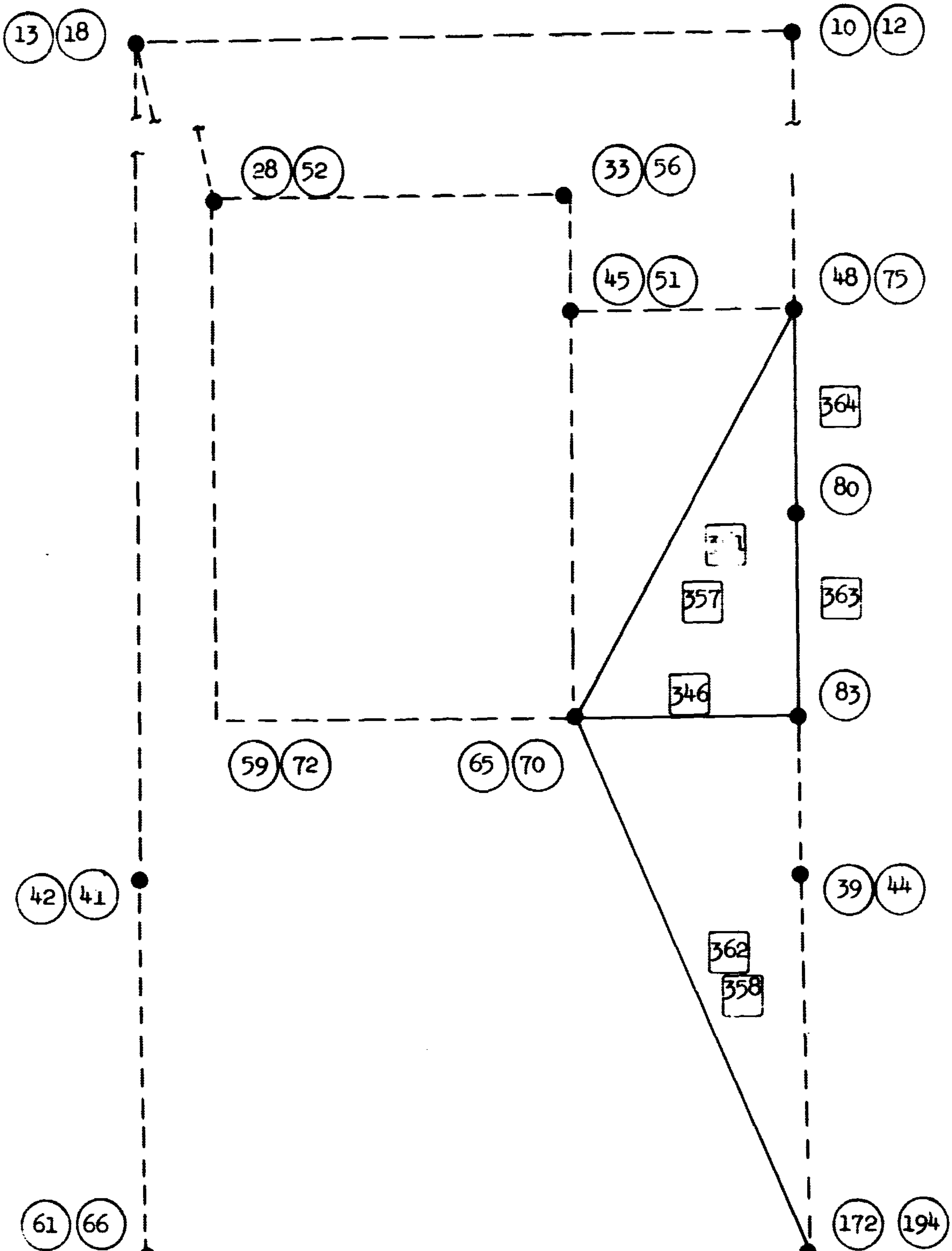

Figure 10.- Idealized structure, diagonal ties, second and fourth quadrant.

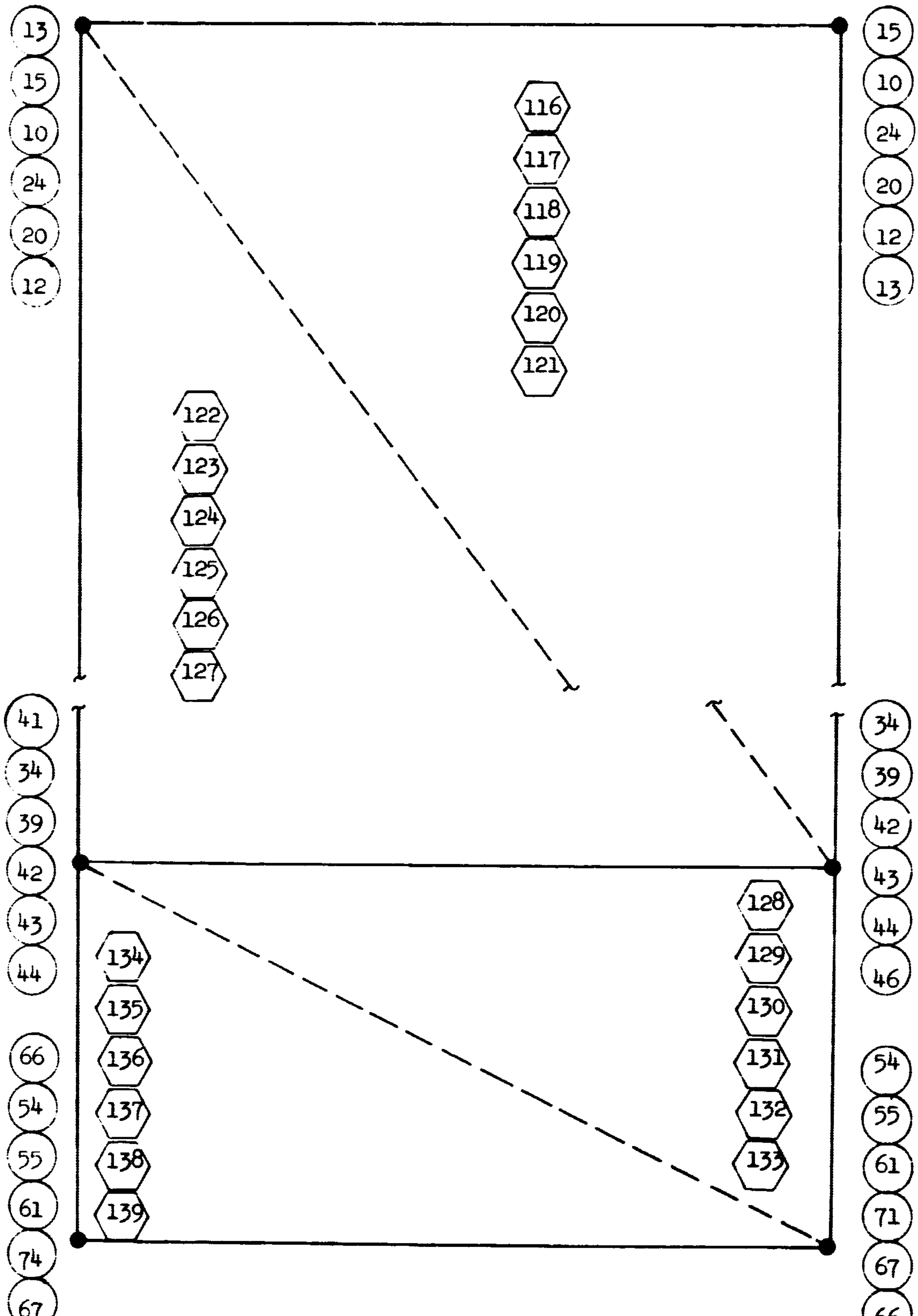

Figure 11.- Idealized structure, solar panels.

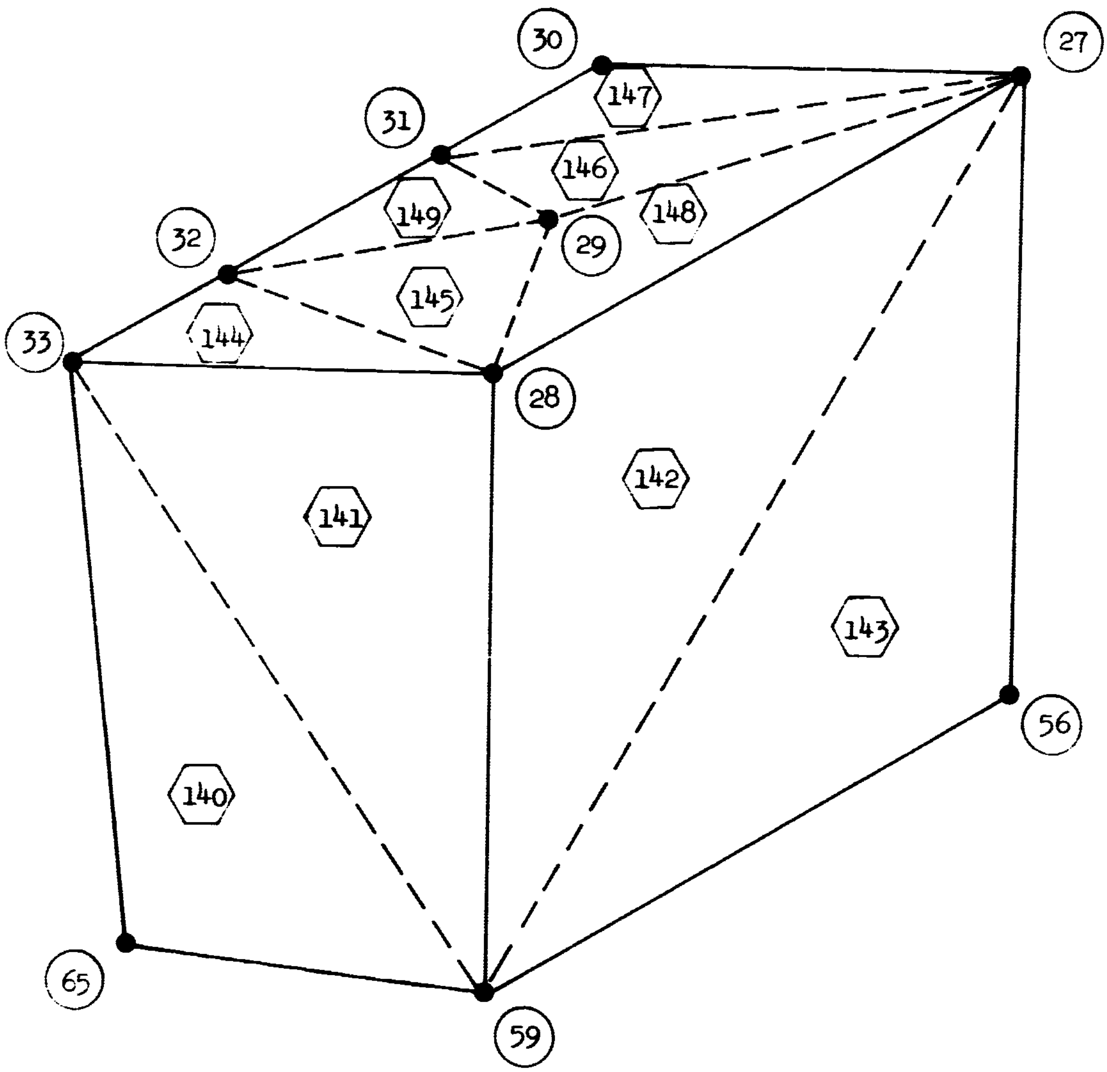

Figure 12.- Idealized structure, card cage No. 1, outer section.

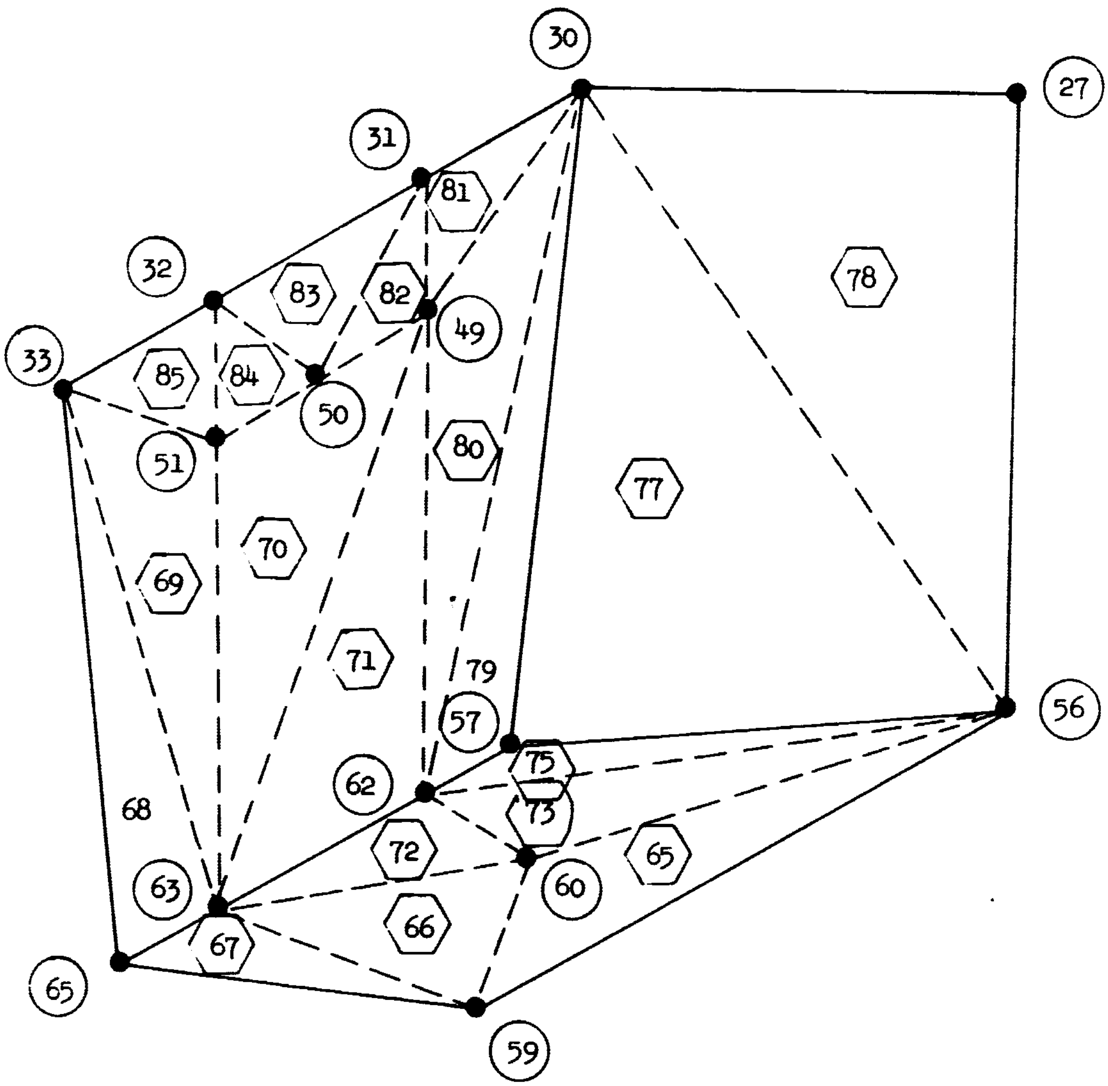

Figure 13.- Idealized structure, card cage No. 1, inner section.

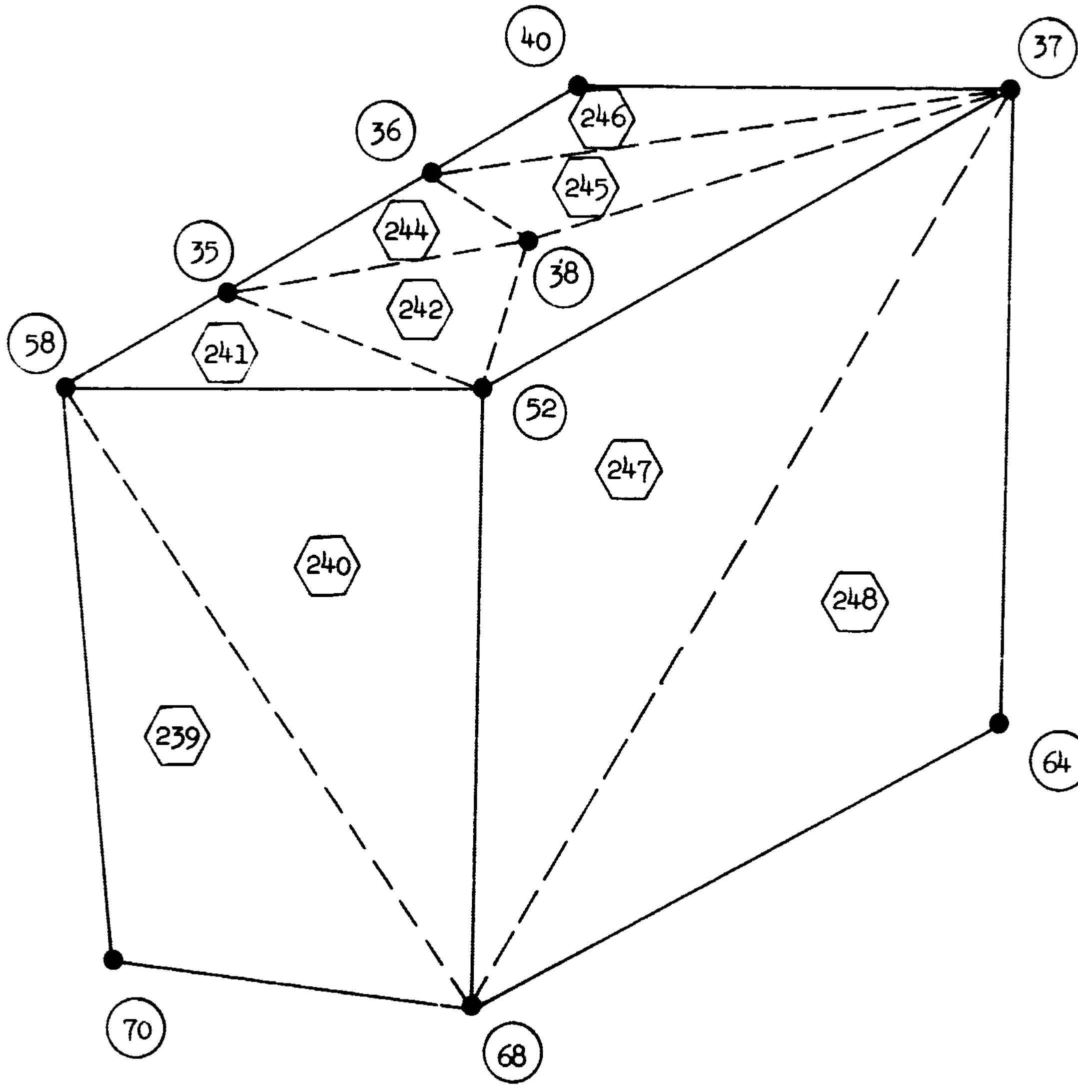

Figure 14.- Idealized structure, card cage No. 2, outer section.

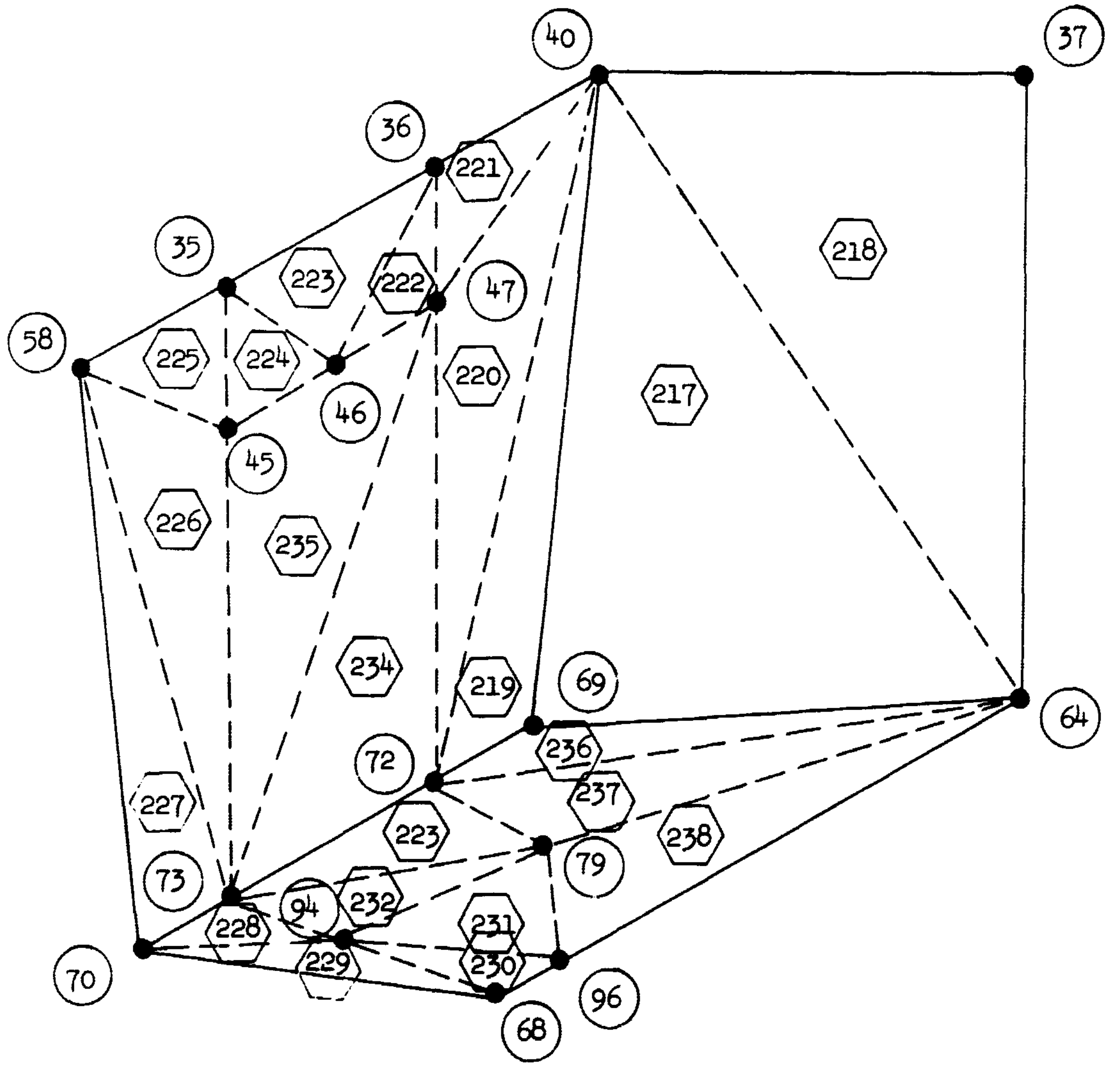

Figure 15.- Idealized structure, card cage No. 2, inner section.

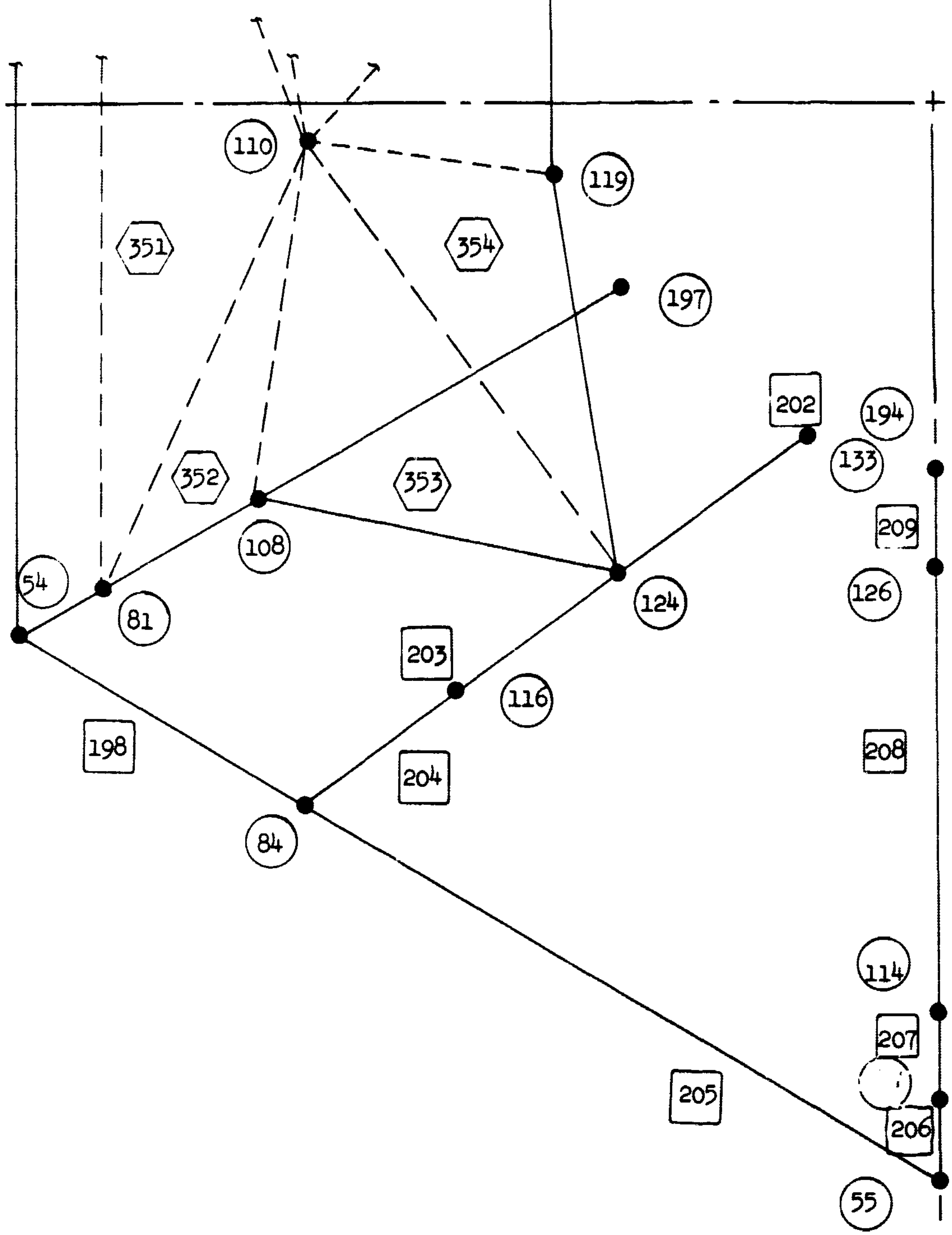

Figure 16.- Idealized structure, bottom plate, first quadrant.

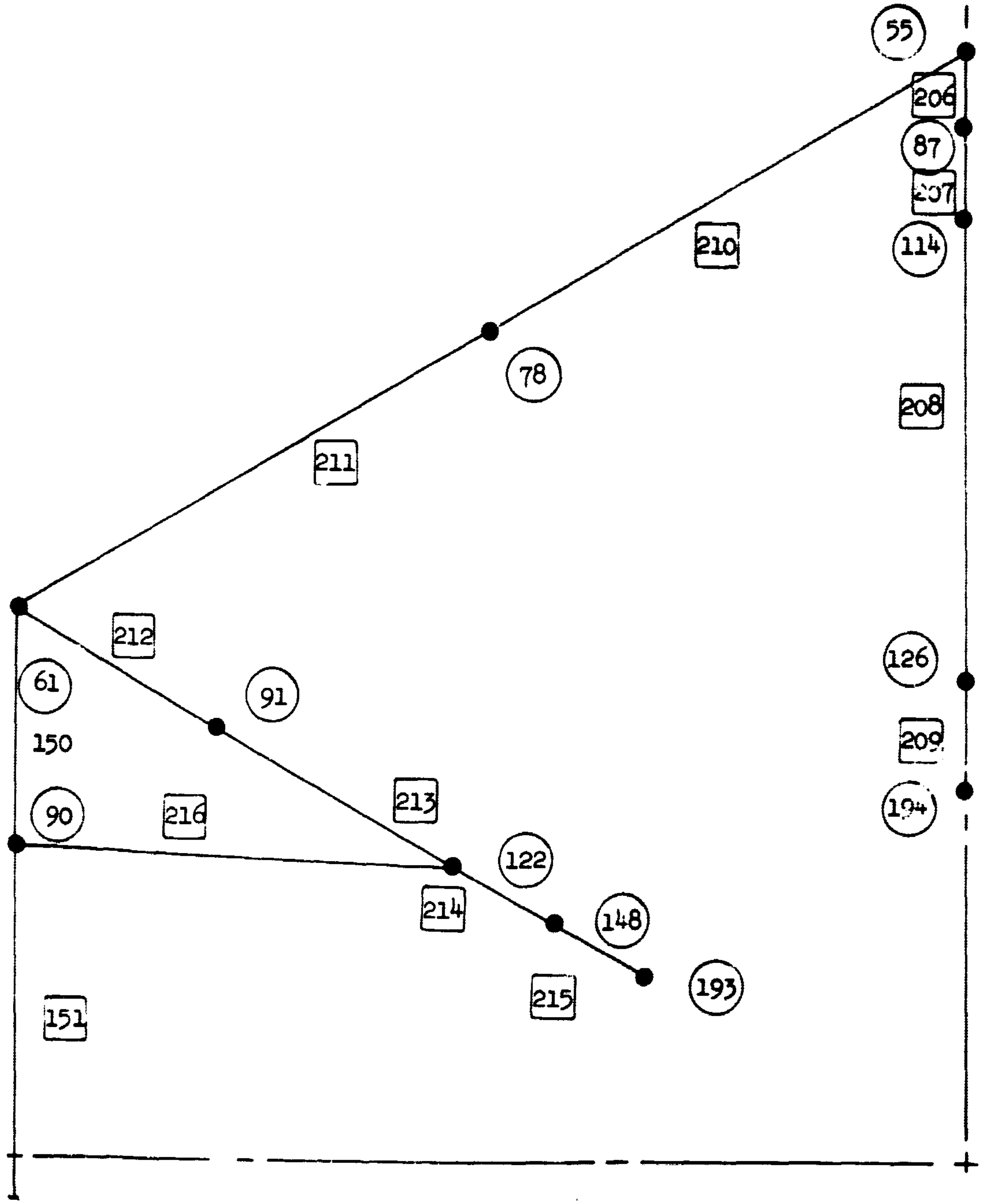

Figure 17.- Idealized structure, bottom plate, second quadrant.

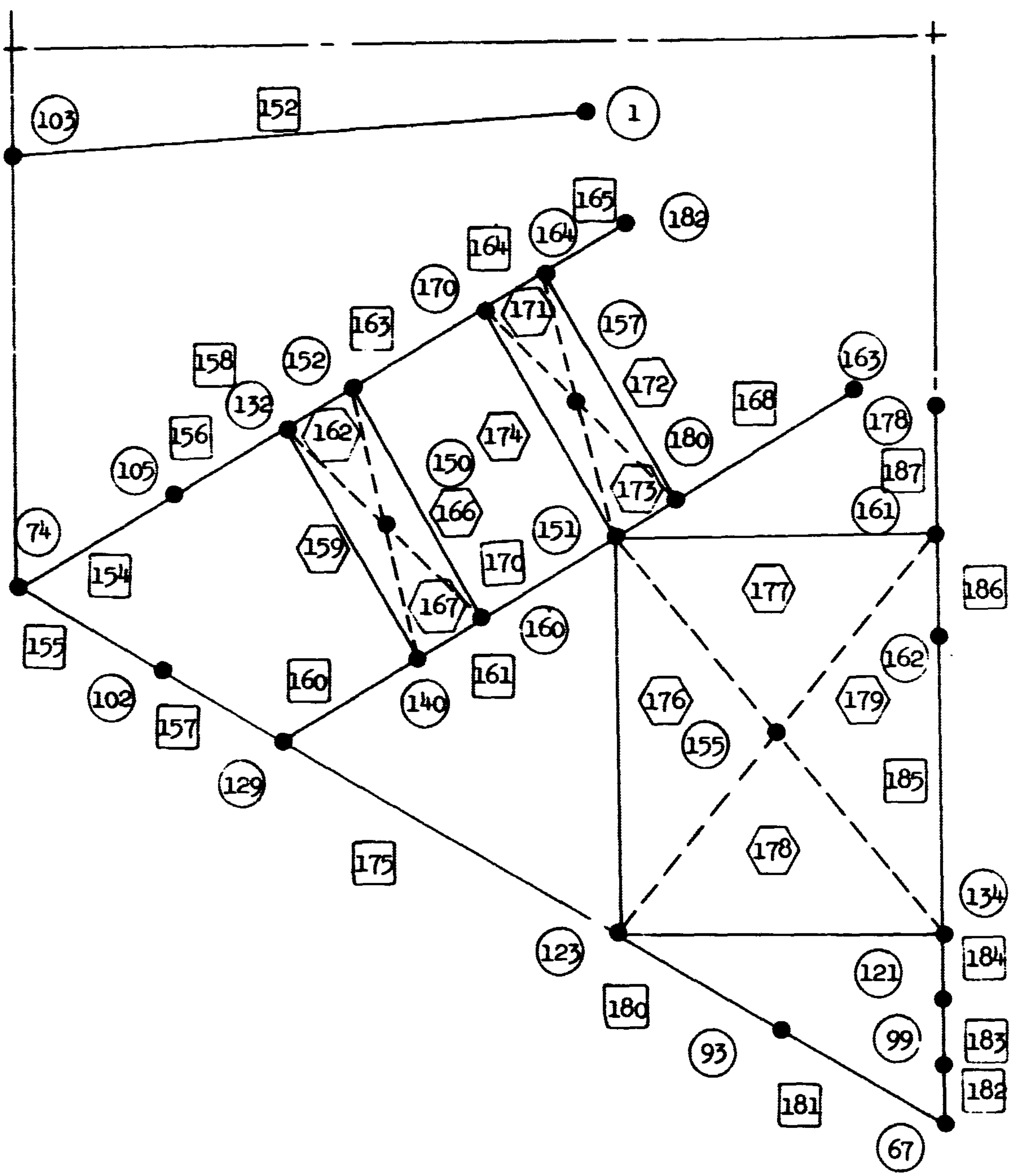

Figure 18.- Idealized structure, bottom plate, third quadrant.

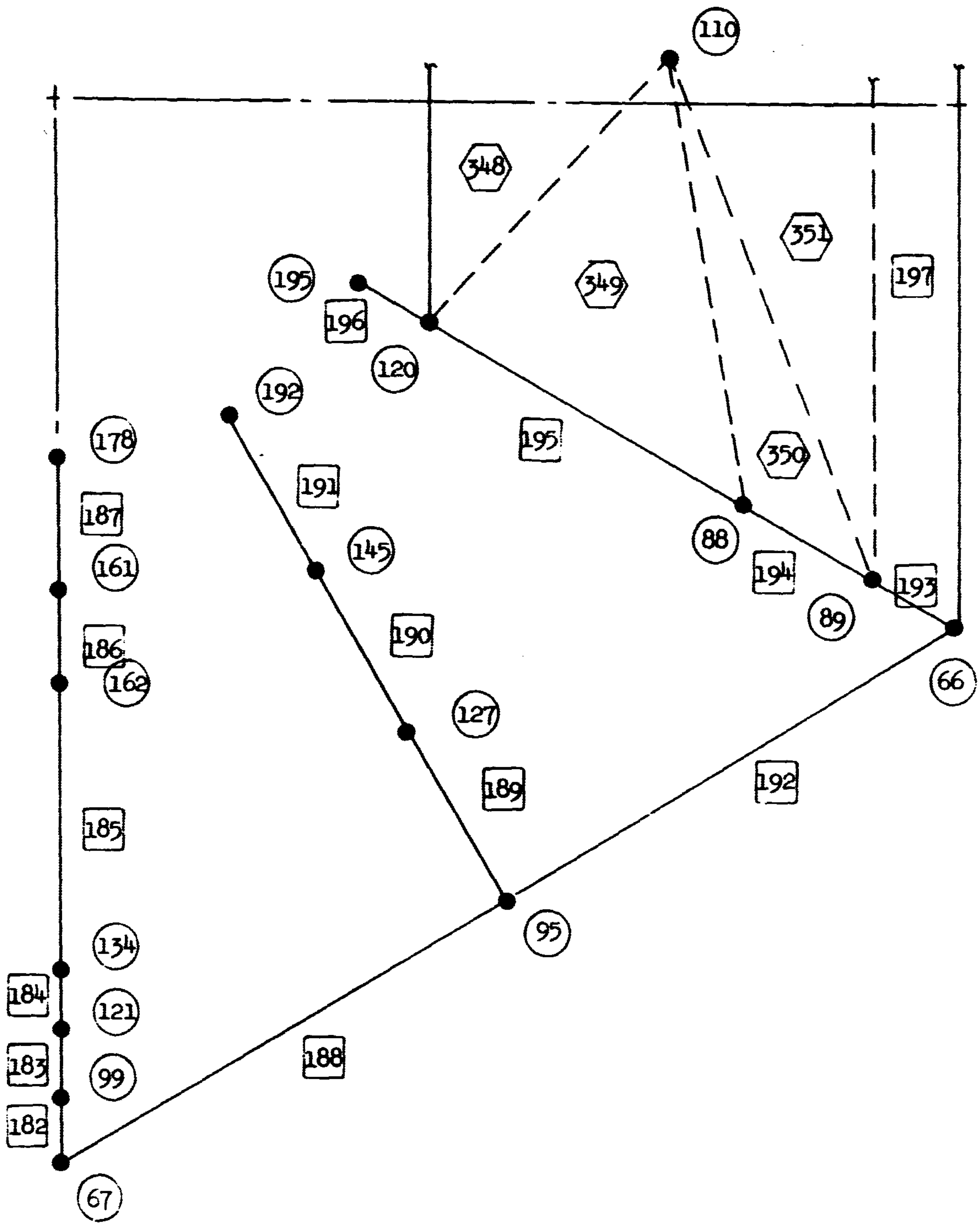

Figure 19.- Idealized structure, bottom plate, fourth quadrant.

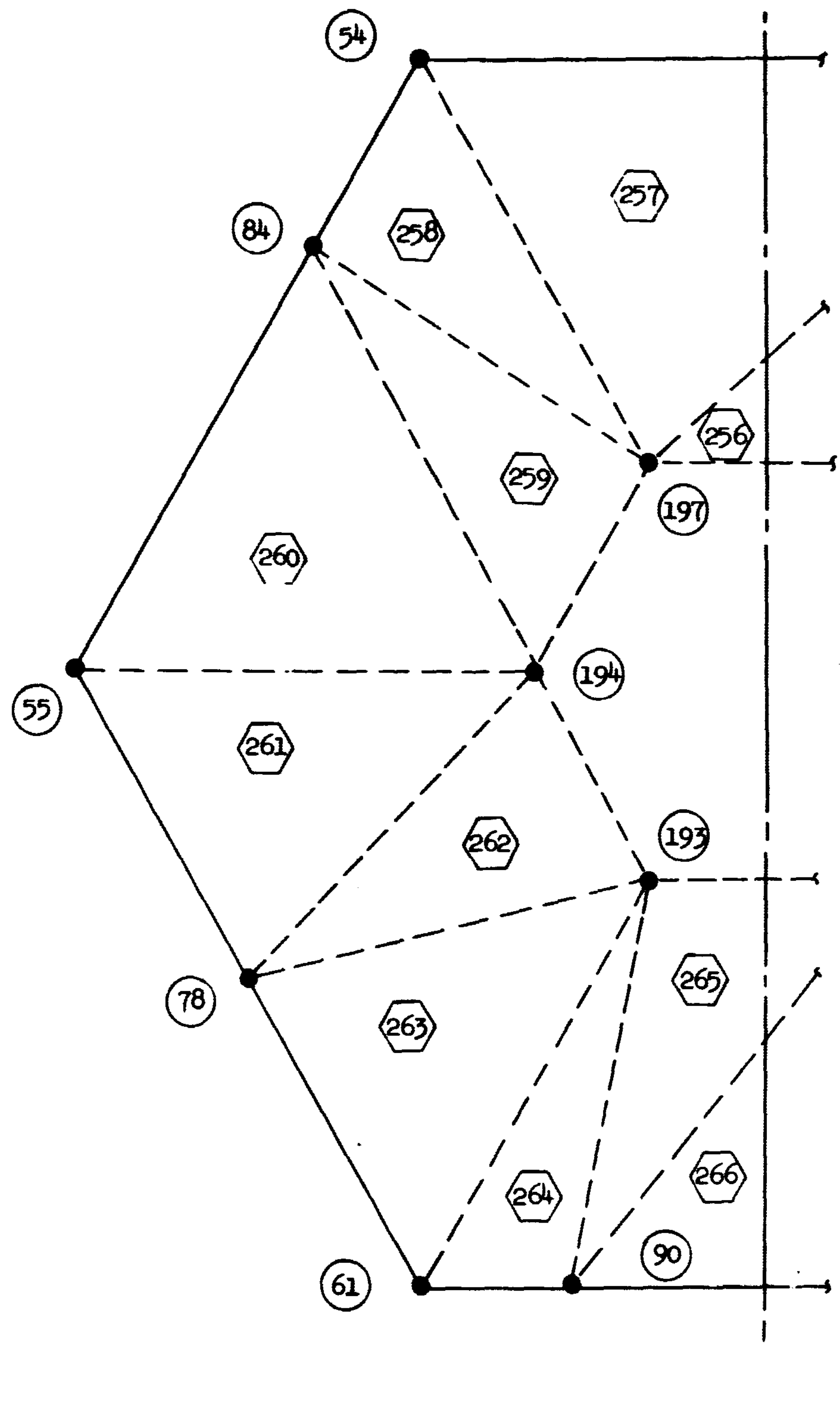

Figure 20.- Idealized structure, bottom plate, panel divisions,

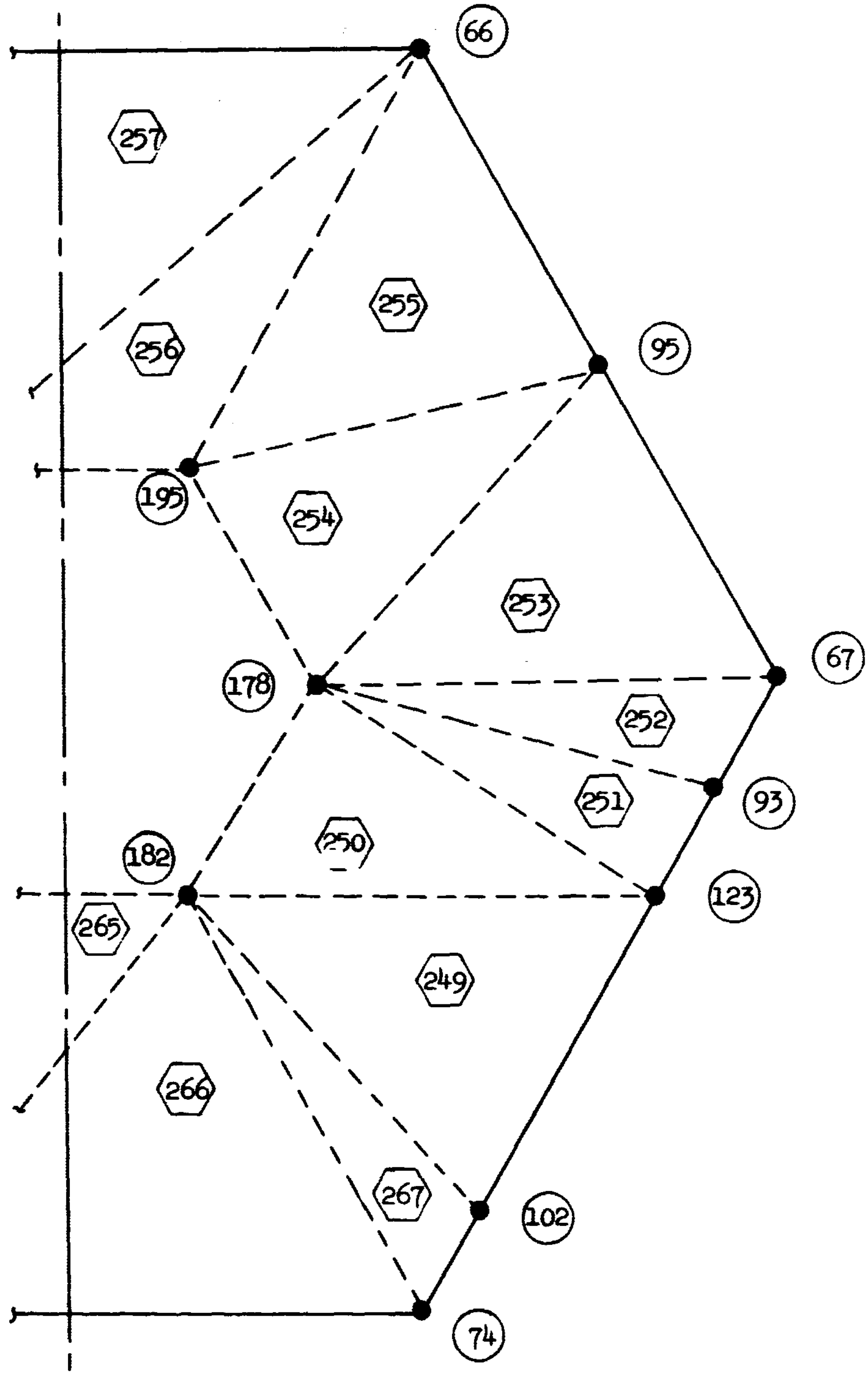

Figure 21.- Idealized structure, bottom plate, panel divisions,

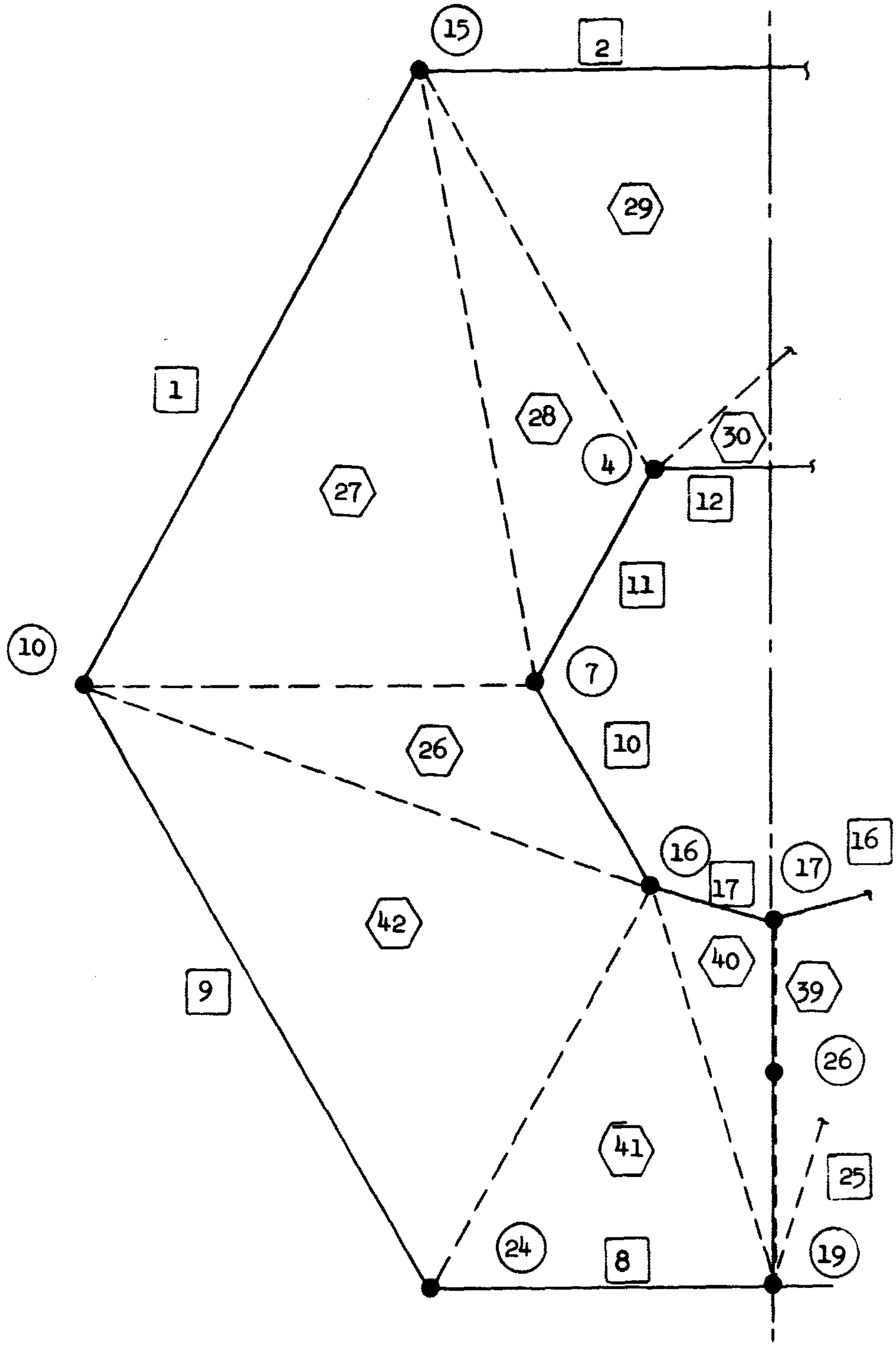

Figure 22.- Idealized structure, top plate, panel divisions, first and second quadrant.

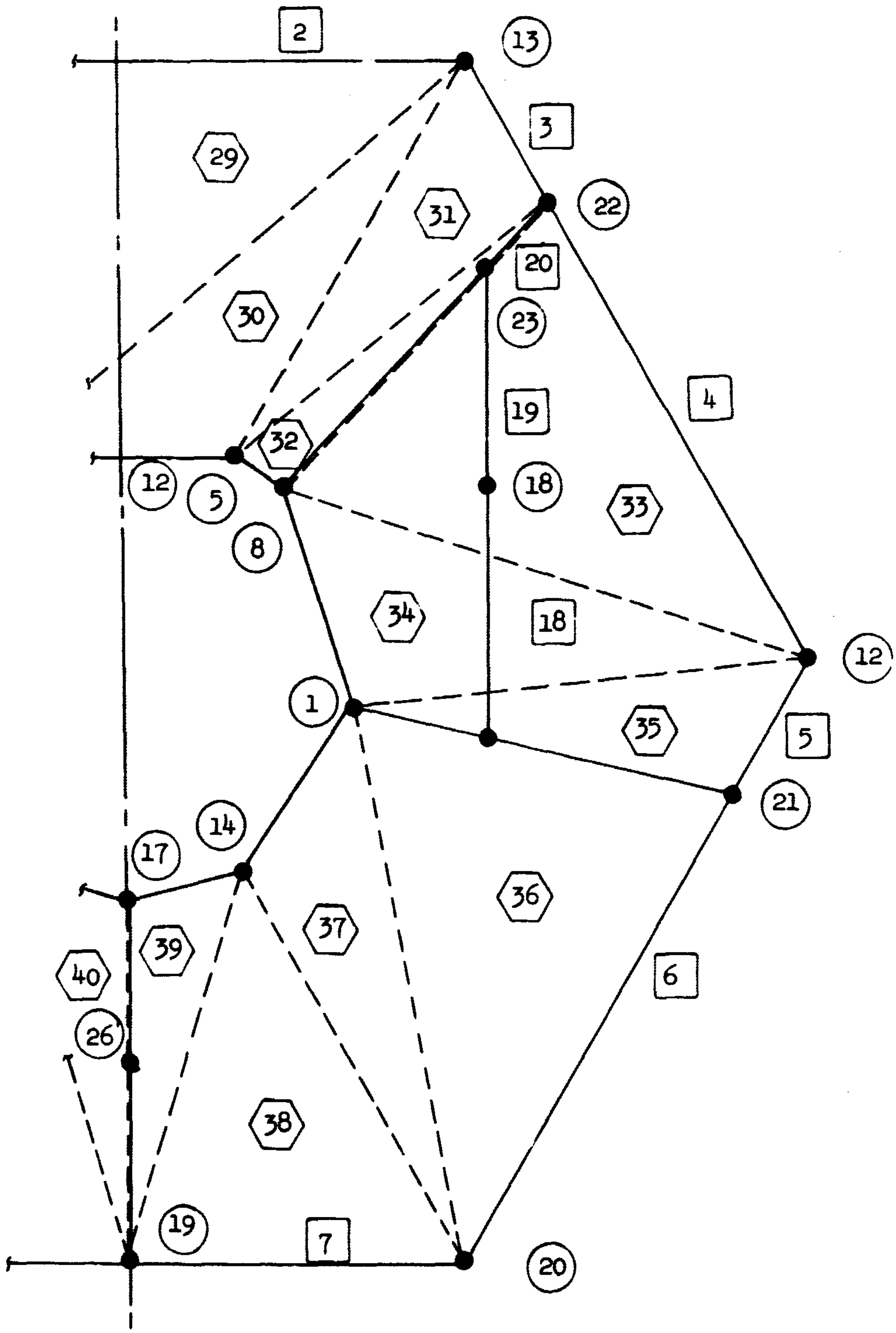

Figure 23.- Idealized structure, top plate, panel divisions, third and fourth quadrant.

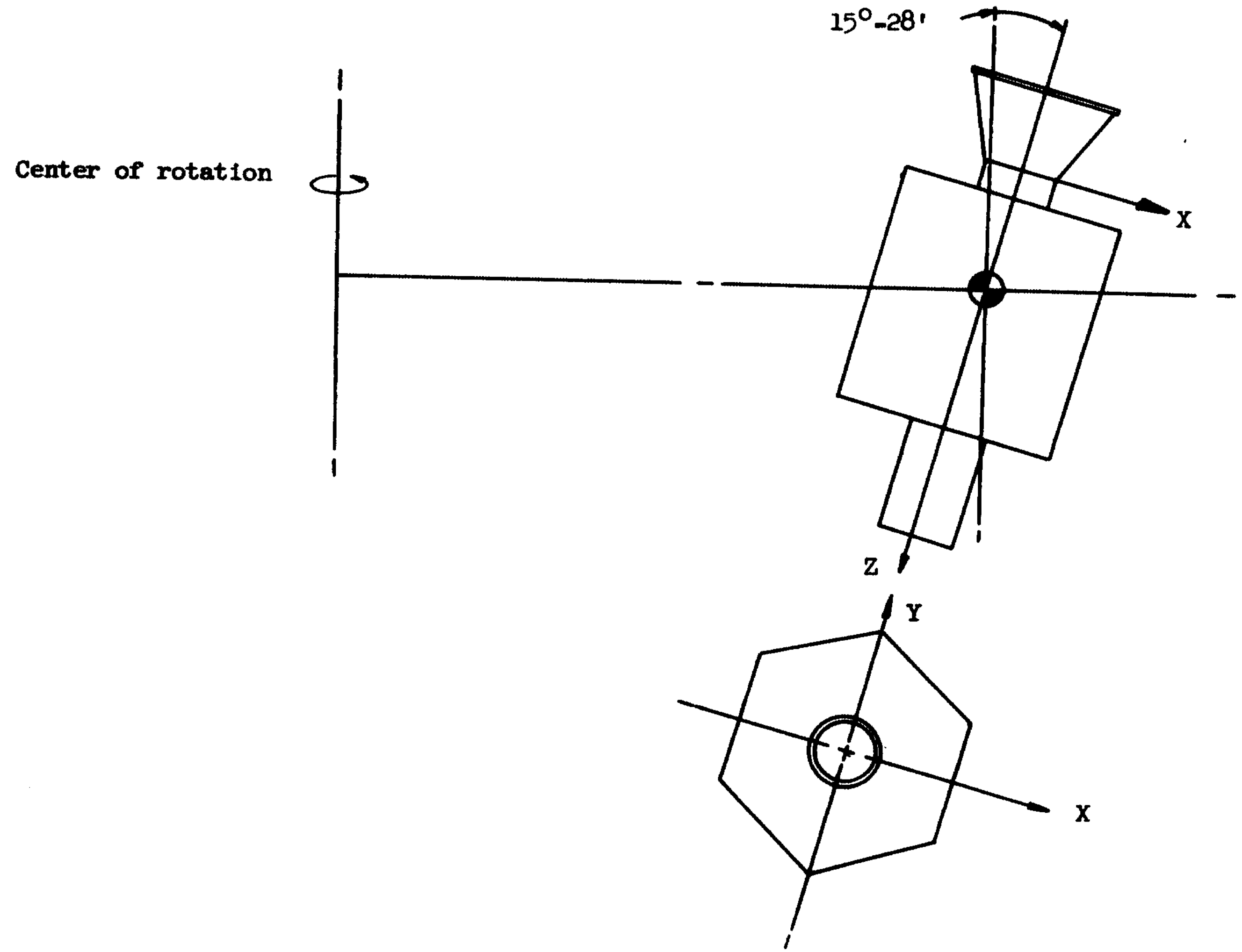

Figure 24.- Spacecraft orientation in centrifuge.

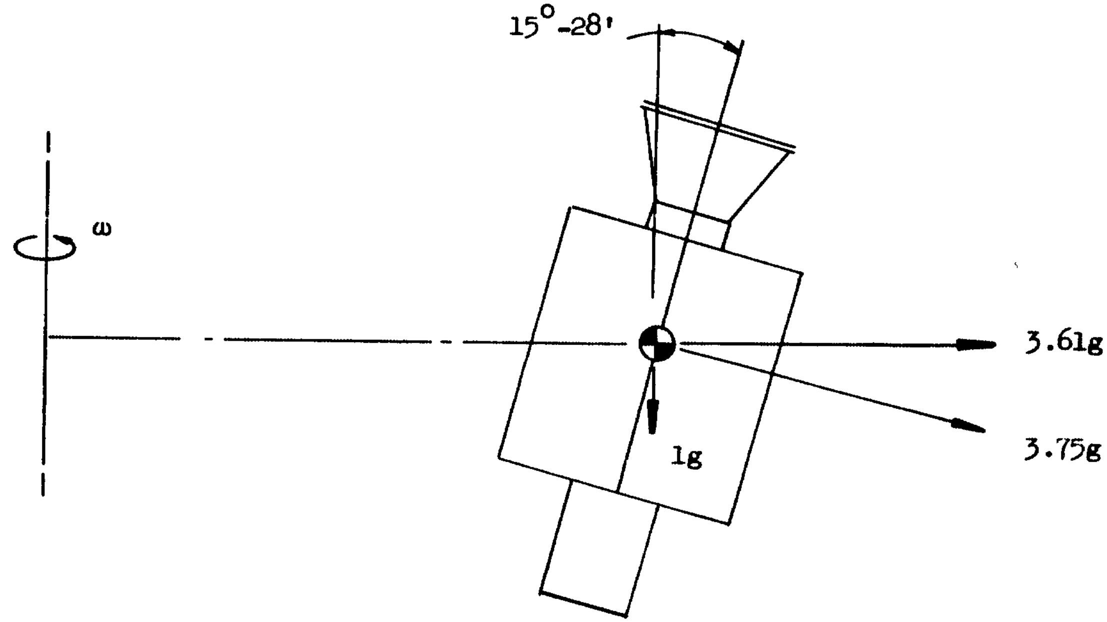

Figure 25.- Applied acceleration.

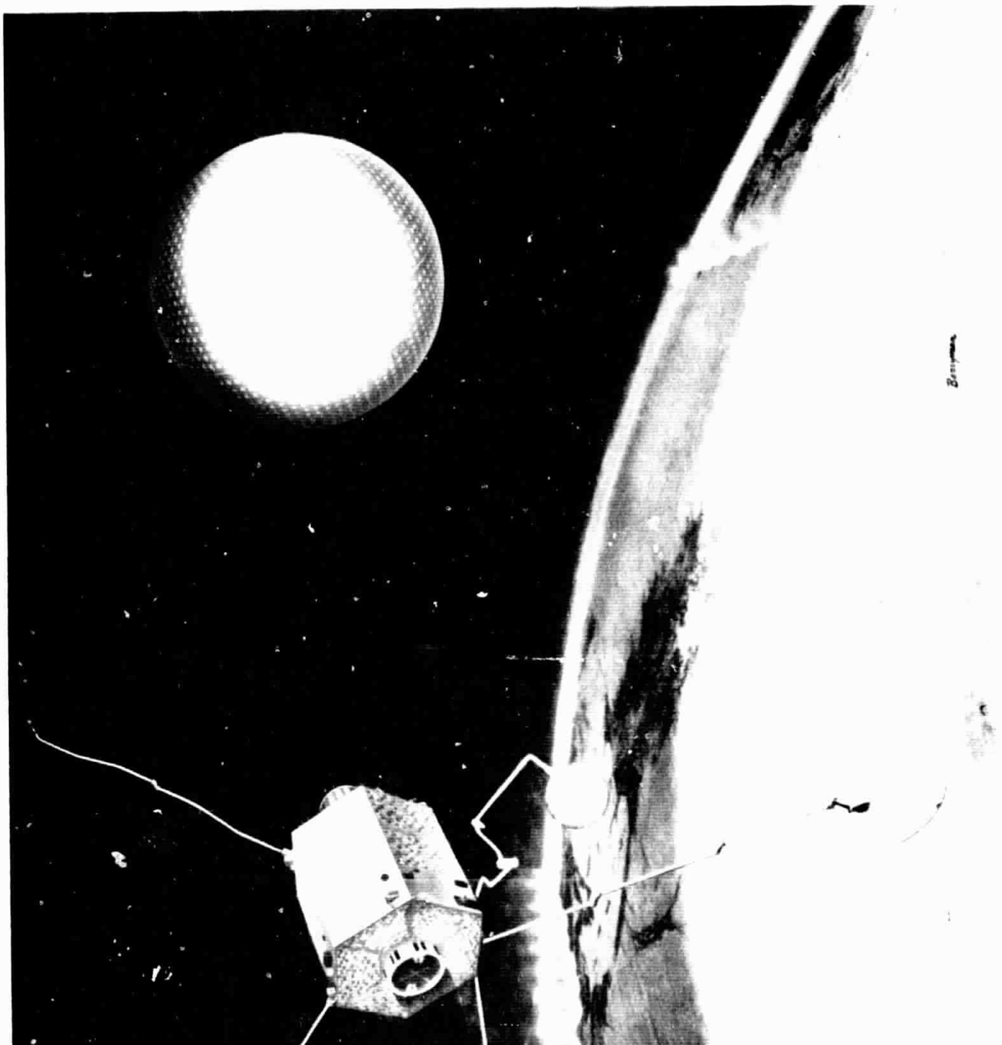

Figure 26.- Spacecraft in orbit.