CHAPTER 4

Braided Composite Frame Test Apparatus and Instrumentation

This chapter details the apparatus and instrumentation for the static tests of the braided composite frames. The dimensional measurements of the frames are presented in Section 4.1. Apparatus and other fixtures needed to conduct the tests are presented in Section 4.2, and the instrumentation is discussed in Section 4.3.

4.1 Frame specimens

As stated in Chapter 1, the J-section frames used in this research were supplied to the NASA Langley Research Center by the Lockheed Aeronautical Systems Company. There are five frames, and they are labeled as A, B, C, D, and CF6F. The frames are circular arcs with an included angle of about 48°. The cross-section of these frames is defined by the dimensional parameters shown in Fig. 4.1. Detailed measurements and the weight of each frame are listed in Table 4.1. Frames A, B, and C were selected for testing. Frame A was used to provide coupons for the material characterization tests presented in Chapter 3. Static tests under a radially inward load are conducted on frames B and C.

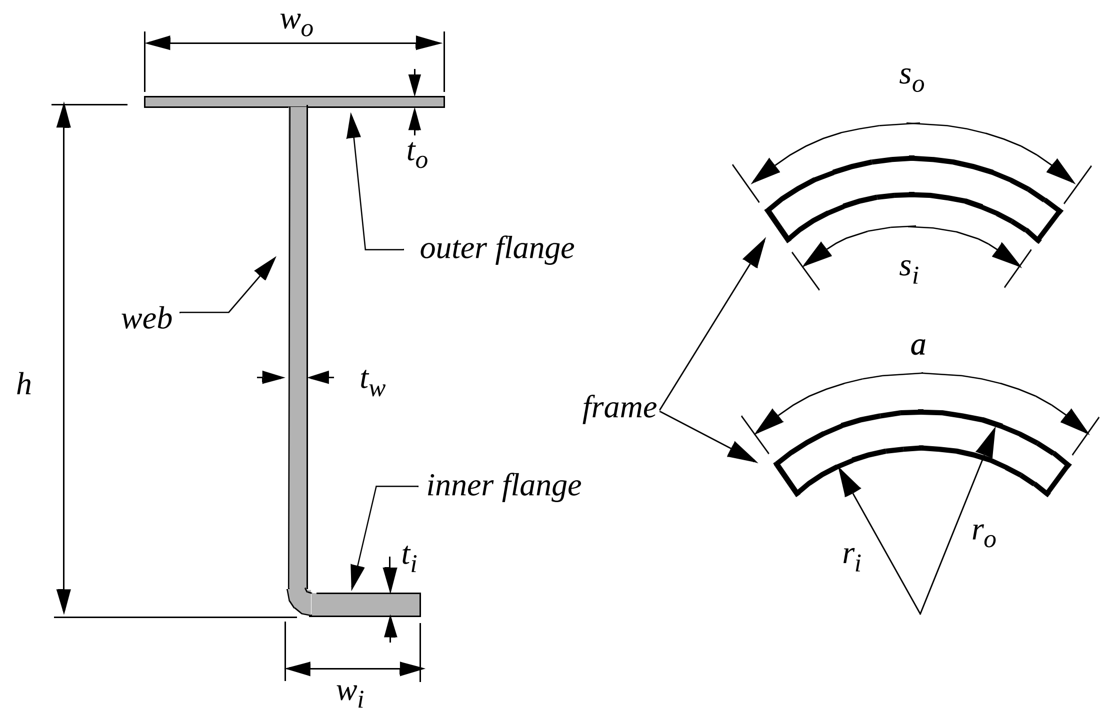

Fig. 4.1 Dimensional nomenclature for the braided composite, J-section frames.

Table 4.1 Braided composite frame measurements and weights.

Parameter (See Fig. 4.1)	**Frame**				
	A	**B**	**C**	**D**	**CF6F**
weight, lb	---	6.74	6.99	6.88	6.80
w_i, in.	1.24	1.25	1.27	1.26	1.27
w_o, in.	2.78	2.77	2.80	2.79	2.80
t_i, in.	0.198	0.204	0.202	0.203	0.200
t_o, in.	0.0892	0.0885	0.0920	0.0892	0.0823
t_w, in	0.162	0.159	0.172	0.177	0.162
h, in.	4.78	4.80	4.81	4.81	4.79
s_i, in.	98.12	98.12	98.12	98.09	97.19
s_o, in.	102.12	102.12	102.09	102.16	101.06
r_i, in.	117.25	117.85	118.92	116.23	120.04
r_o, in.	122.03	122.65	123.73	121.04	124.83
a, degrees	48.18	47.21	47.46	47.56	47.09

4.2 Test apparatus

To apply a radially inward load at the apex of the circular section frame, the frame is mounted vertically in a universal testing machine. This Baldwin testing machine is the same one used to test the composite frames made of unidirectional tape. The braided frame is held in position within the testing machine by an assembly consisting of a steel I-beam and two end blocks bolted to the top flange of the I-beam. The end blocks have slots machined in them in the shape of the cross section to receive the ends of the frame. A potting material is used to secure the frames in the slots of the end blocks. Since the braided composite frame specimens are larger than the tape layup ones, a larger beam is required to support the specimen. This beam is clamped to the moveable table of the load frame by C-clamps. Since the frame segment spans about eight feet and the I-beam is ten feet long, the assembly is placed diagonally on the table of the testing machine to avoid interference with the columns of the load frame and provide a longer support for the I-beam. A schematic of the test apparatus is shown in Fig. 4.2. The specimen is loaded in a displacement-

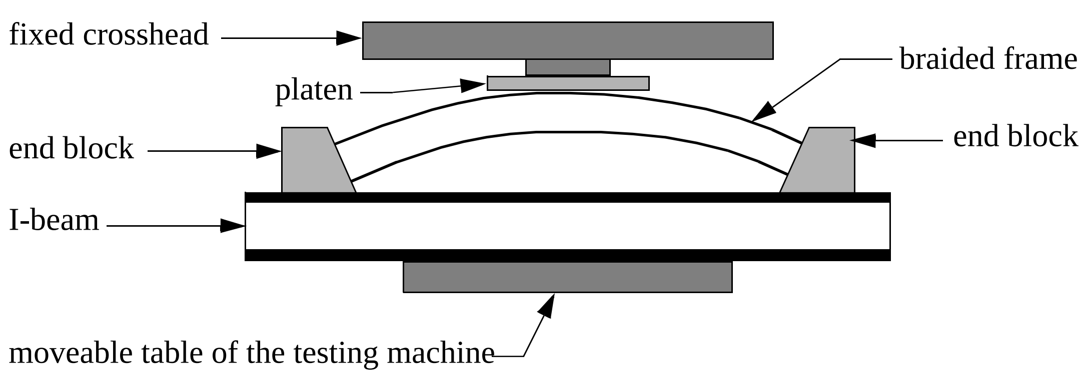

Fig. 4.2 Schematic of the apparatus in the braided frame test.

controlled test by moving the table upward so that the apex of the frame contacted a platen attached to the fixed crosshead of the load frame. The designs of the I-beam, platen, and end blocks are discussed in the following sub-sections. Frame B mounted in the load frame prior to testing is shown in Fig. 4.3

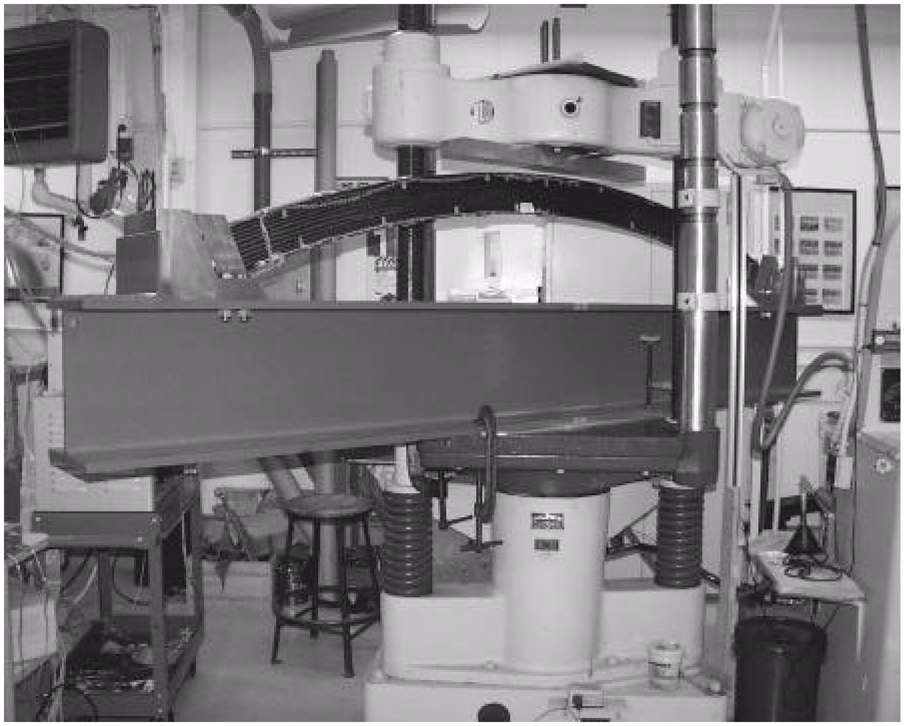

Fig. 4.3 Braided composite frame B mounted in the load frame prior to the test.

4.2.1 Frame analysis

The finite element computer code PROFAIL (Woodson, 1994) is used to determine the support reactions and to estimate the maximum load for the braided frame. Details of the required input files and how to execute PROFAIL are discussed in Appendix 1. The frame is modeled as forty-two degree sector, clamped at each end, and subjected to a radially inward point force *F* at its apex. See Fig. 4.4. The cross-sectional stiffness matrix for the frame is determined using the material properties from the tension and bending tests of the braided coupons discussed in Chapter 3. The cross-sectional stiffness matrix computed in the PROFAIL code was originally developed to analyze walls laminated from tape layup composites, not braided composites. To model the braided wall construction, the wall is taken as a single layer of material with the material properties obtained from the coupons tests. The properties that were not available from the tests were selected from the results of computer code TEXCAD listed in Table 3.14 on page 75 for the $[0°_{18k}/\pm64°_{6k}]$ 39.7% axial braided composite material. Since the coupon test results were so close to the TEX-CAD prediction, the properties selected for braided frame analysis are the ones obtained

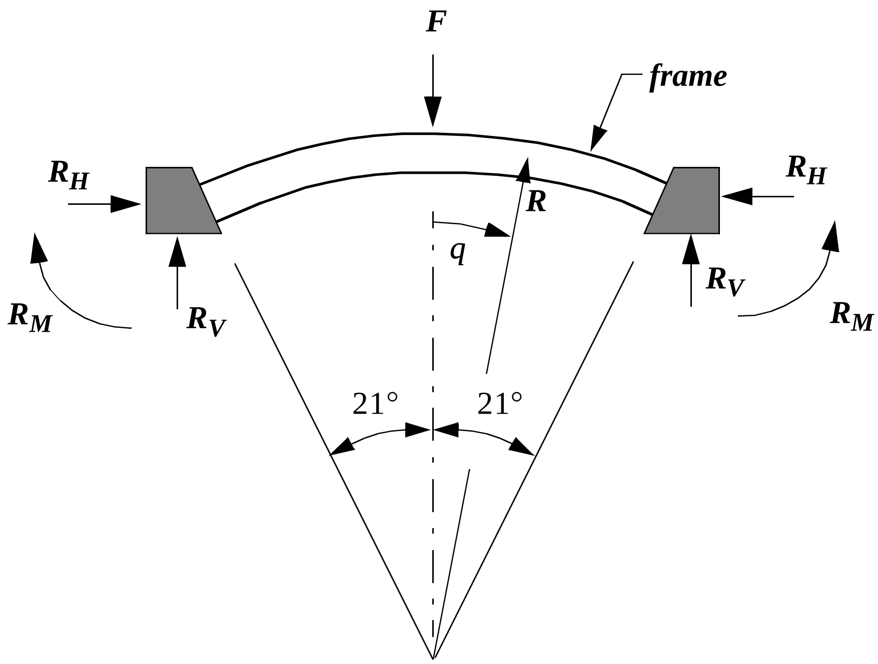

Fig. 4.4 The braided composite frame configuration used in PROFAIL.

from the computer code TEXCAD. These material properties are summarized in Table 4.2. The output of the code include the reactions at the ends, displacements and rotations along the span of the frame, and data to construct the load-deflection curve. The analysis using this code yields the following results: maximum load F = 14087 lb, maximum displacement $\boldsymbol{d}$ = 0.629 in. (displacement at the point of application of F in the direction of F), horizontal reaction R_H = 1.58 F lb, vertical reaction R_V = 0.500 F lb, moment R_M = 0.947 F lb-in.   The failure analysis of Woodson's code, as was stated in Chapter 2, is

Table 4.2 Braided frame material properties used in PROFAIL.

Stiffness Properties	**Value**	**Strength Properties**	**Value**
Longitudinal modulus, E_1,	7.06 Msi	*Longitudinal tension, X*	91.37 Msi
Transverse modulus, E_2,	6.59 Msi	*Longitudinal compression, X'*	71.00 Msi
Major Poisson's ratio,ν_{12}	0.231	*Transverse tension, Y*	73.14 Msi
Shear modulus, G_{12},	1.91 Msi	*Transverse compression, Y'*	56.89 Msi
		Shear, S	30.46 Msi

based on Tsai's selective and progressive failure model for laminates fabricated from graphite-epoxy tape. Hence, the failure predictions from PROFAIL code are not really applicable to the braided textile frames. However, the failure load predicted by the PROFAIL code is used to design the end fixtures for the test. In TEXCAD, Naik (1994b) implemented several failure criteria, as is discussed in Chapter 1, but these failure criteria were not programmed into PROFAIL code.

4.2.2 Design of the wide flange support beam

The reactions obtained from the analysis using the PROFAIL code are imposed as loads in a separate analysis of the I-beam to support the frame The I-beam is specified as a wide flange (WF) steel beam, and its dimensions are determined such that its maximum displacement is less than one percent of the maximum displacement of the frame at the failure load. The I-beam is assumed to lay flat on the movable table of the testing machine, but the diagonal dimension of the moveable table is less than the length of the I-beam. Hence, the I-beam overhangs the movable table, and the overhang length L is depicted in Figure 4.5. In this figure $L = (L_1 - L_2) / 2$, where length L_1 is the span of the braided frame, and L_2 is the length of the moveable table on which the I-beam rests. The deflection analysis of the I-beam assumes the I-beam in the overhang is a cantilevered beam of length L with loads applied at the tip. Since the loads are the reactions from the frame analysis, they are assumed to act on the top flange of the I-beam. The vertical load applied to the cantilever is the reaction force R_V (= F/2) as shown in Figure 4.4, and the moment $M_0 = R_M + (h/2) R_H$, where h denotes the height of the I-beam in its cross section. Castigliano's theorem is used to calculate the vertical displacement and rotation at the tip. Let d_z denote the tip displacement, and let q_y denote the rotation at the tip in the plane of the beam. The tip displacement is

$$\delta_z = [(M_o L^2)/2 - (FL^3)/6]/(EI_{yy}) \tag{4.1}$$

and the rotation is

$$\theta_y = (M_0 L - (FL^2)/4)/(EI_{yy}) \tag{4.2}$$

where EI_{yy} denotes the bending stiffness of the beam with respect to bending in the longitudinal plane (x-z plane). A 10 ft.-long, W14 x 82 steel beam is selected based on limiting the tip displacement to 1% of the maximum frame displacement.

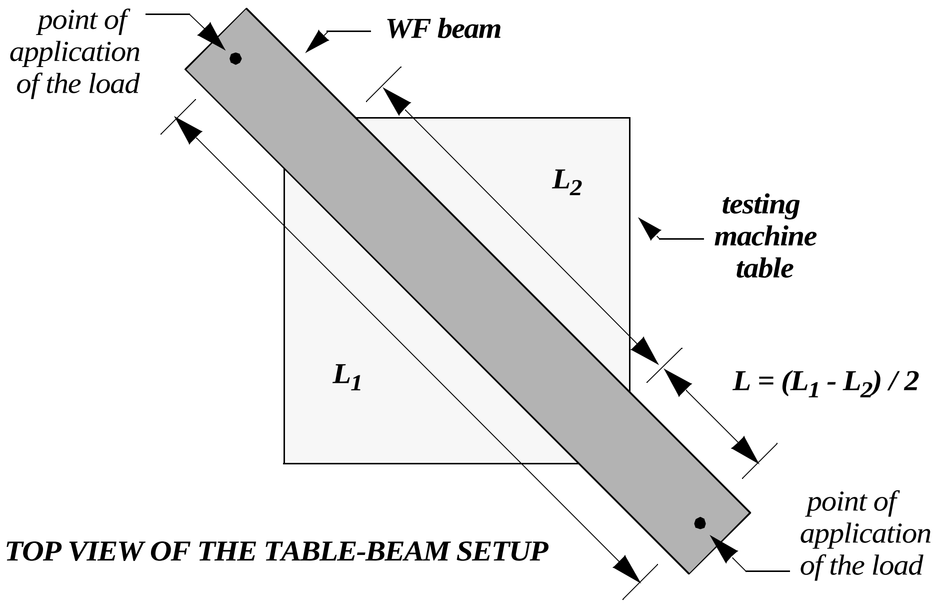

Fig. 4.5 Top view of the machine table-beam setup showing the definition of overhang length *L* used in the I-beam analysis.

4.2.3 Platen design

The bottom surface of the cross head of the testing machine is not flat, and so does not provide a good contact surface for the radially outboard flange of the frame. A flat plate, or platen, is attached to the cross head to provide a smooth, flat surface for the frame to contact in the test. The platen is sized assuming it is a bar pinned at two equidistant points six inches from the center of the bar, and that the bar is subjected to a triangular distributed load. Although the distribution of the normal contact force between the frame and the platen is not known, the triangular distribution is assumed for the sake of simplicity. The length of contact zone is denoted by L, and it is assumed to be the length of the horizontal chord connecting two points on the outside radius of the frame defined by the vertical displacement, d, of the apex frame at the maximum value of the force F. Refer to Section

4.2.1. That is, $L = 2\sqrt{2R\delta + \delta^2}$, and the value of this contact length is computed to be 24.87 inches. The configuration and load acting on the bar is shown in Fig. 4.6. In this fig-

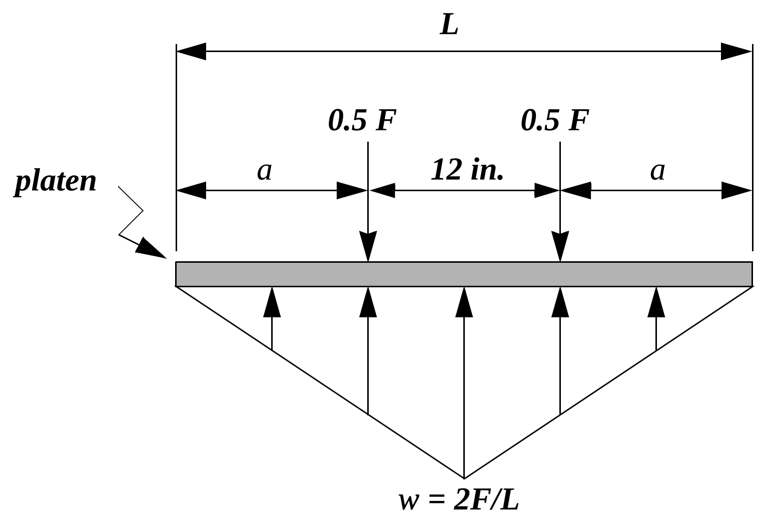

Fig. 4.6 Configuration and load assumed for the analysis of the platen.

ure the value of the distributed load intensity at the center of the bar, ω, is *2F/L*. Symmetry implies that the rotation at the center of the bar due to bending, and the shear force at the center of the bar, both vanish. Using formulae from Mechanics of Materials (Young, 1992), for L = 24.87 inches and a = 6.44 inches, where length a is shown in Fig. 4.6, the upward vertical displacement at the center of the bar, d_v, is determined as

$$d_v = (-240052 + 35987\,x + 0.7588866\,x^5 - 1174\,\langle x - 6.44\rangle^3) \,/\, EI \qquad (4.3)$$

where EI is the bending stiffness of the bar.

The design constraint for the platen is the same as for the I-beam; that is, the maximum deflection in the platen is less than one percent of the maximum deflection in the frame. On this basis of limiting the platen’s displacement, an aluminum bar 32 in. long, 4 in. wide, and 2 in. depth is selected for the platen.

4.2.4 Securing the frame in the end blocks

The fixtures used to clamp the ends of the frame to the beam consisted of two steel blocks 10 in. long, 8 in. high, and 8 in. wide. Each block consisted of two pieces, denoted by A and B, that are fastened together by machine screws. Two opposite sides of piece A are machined parallel at an angle of 24° with respect to the vertical. A slot in the shape of the cross section is bored through the five-inch depth of these inclined sides. Piece B is solid and is bolted to the back of piece A. The two piece assembly facilitated the removal of the frame from the block at the end of the test. See Figure 4.7. The slots in piece A are approx-

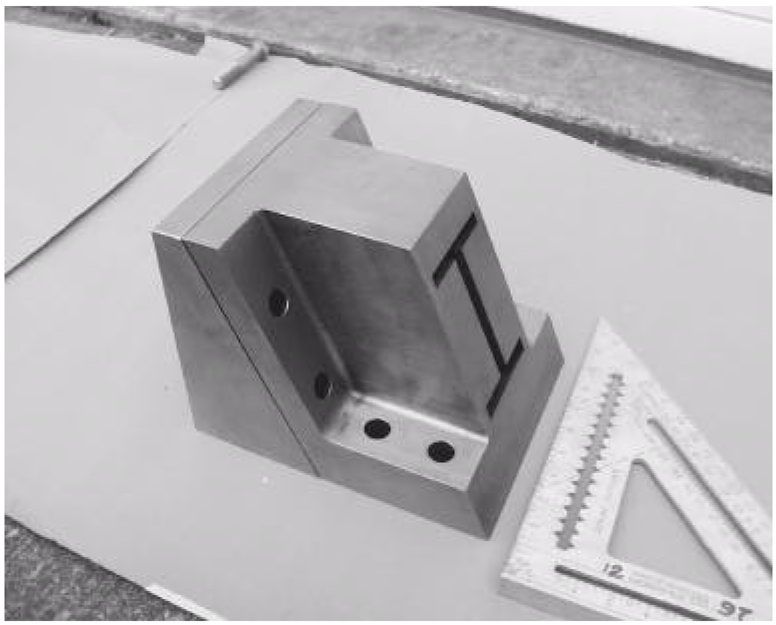

Fig. 4.7 End block.

imately 0.25 in. wider than the thicknesses of the frame's web and flanges, and a potting compound is used to fill this gap.

The end blocks are bolted to the I-beam and the ends of the frame ends are inserted into slots of piece A of each block to a depth of five inches. Each end of the frame is then centered in the slot with small aluminum and steel shim stock. The assembly is then lifted on one side such that the slot in the end block on the opposite side is vertical. A large plastic syringe and an air pump are used to inject a mixture of 20% glass beads and 80% epoxy by weight into the gap between the frame and the vertically aligned slot. After the mixture hardened, the assembly is lowered to the floor, and the opposite end of the assembly is lifted from the floor to repeat the potting procedure in the other end block. With the frame mounted in the fixture, the included angle of the unsupported arc length of the frames reduces from 48° to about 42°, since 5 in. of each end are inside the end blocks.

4.3 Instrumentation

Both braided frames B and C are instrumented with electrical resistance strain gages. These consist of uniaxial gages, two-element rosettes, and three-element rosette gages. Up to 45 channels of strain, plus vertical load and vertical displacement, are recorded in each test. Details of the strain gage lay out on frame B are shown in Figs. 4.8 and 4.9, and in Table 4.3. Frame B was tested first, and after the results of this first test it was decided to use additional instrumentation in the test of frame C. Out-of-plane displacement measurements of frame C are recorded at two circumferential locations $q = 0°$ and $q = -5°$ using linear variable differential transformers (LVDT's). (Note that $q = 0°$ at the apex of the frame.) Also an inclinometer is attached to frame C at $q = -12.5°$ to measure the angle of twist of the frame. Details of the strain gage lay out on frame C are shown in Fig. 4.10, and in Table 4.4. The analog data signals from the transducers are converted to digital form and recorded on a computer hard disk. LabView, a commercial software package from National Instruments, is utilized to condition, process, and convert the data to engineering units for further manipulation.

The upward displacement of the movable table of the Baldwin testing machine is controlled such that the initial loading rate applied to the frames is about 6000 lb per minute. The stroke of the hydraulic machine is limited to approximately 2 in., which is sufficient to observe the first few major failure events. There is some concern that the testing machine would be exposed to high lateral, or side, loads at a major failure event, and limiting the stroke provides some protection against this eccentric load condition occurring.

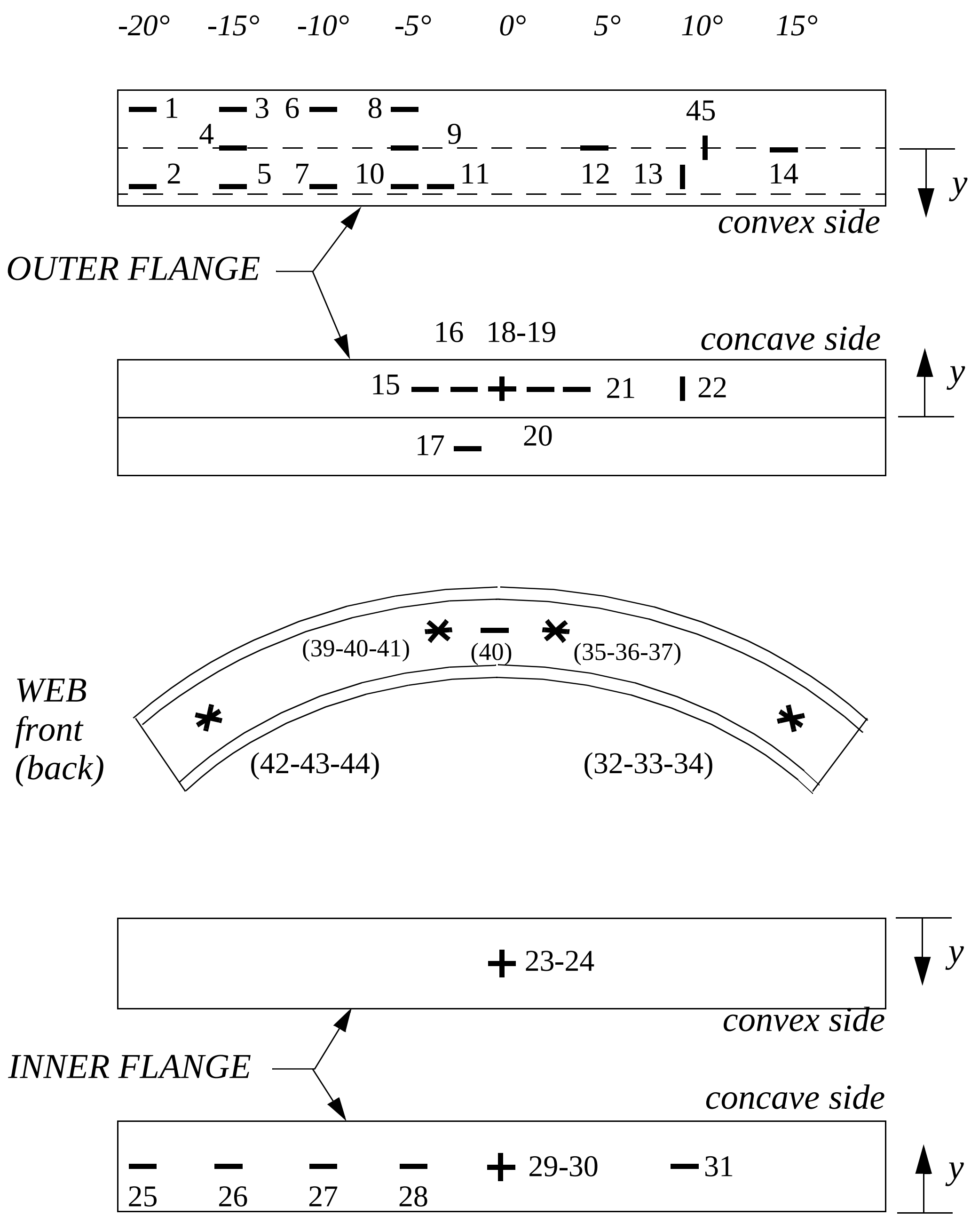

Fig. 4.8 Strain gage lay out on braided composite frame B.

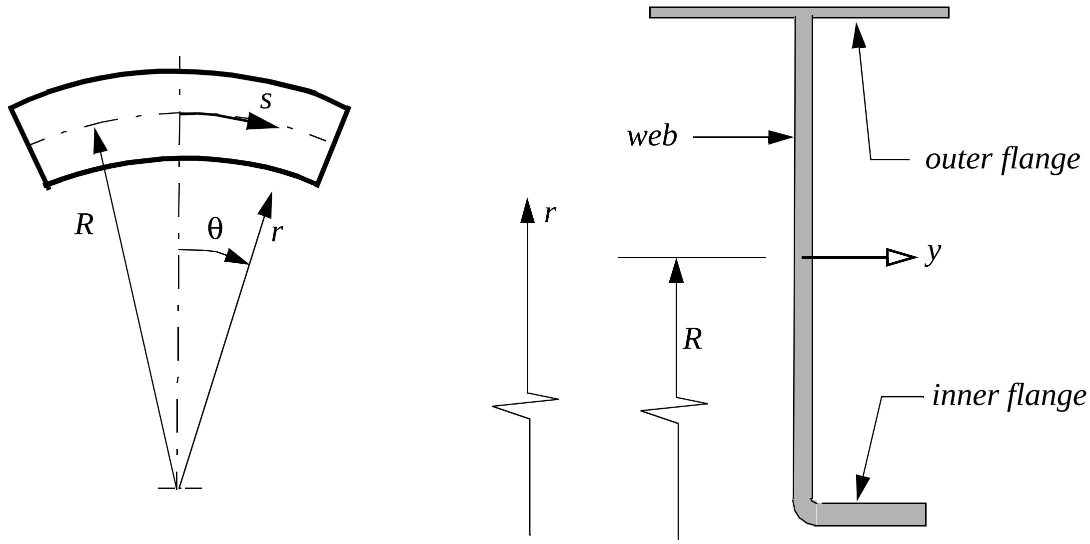

Fig. 4.9 Definition of coordinates in Tables 4.3 and 4.4.

Table 4.3 Circumferential, out-of-plane, and radial locations of strain gages on braided composite frame B.

strain gage #[a]	angle *q*, degrees	s, in.[b]	y, in.[a]	radius r, in.
1	-20	-42.81	-0.693	122.65
2	-20	-42.81	0.693	122.65
3	-15	-32.11	-0.693	122.65
4	-15	-32.11	0	122.65
5	-15	-32.11	0.693	122.65
6	-10	-21.41	-0.693	122.65
7	-10	-21.41	0.693	122.65
8	-5	-10.70	-0.693	122.65
9	-5	-10.70	0	122.65
10	-5	-10.70	0.693	122.65
11	-2.5	-5.35	0.693	122.65
12	5	10.70	0	122.65
13	10	21.41	0.693	122.65

Table 4.3 Circumferential, out-of-plane, and radial locations of strain gages on braided composite frame B.

strain gage #[a]	angle *q*, degrees	s, in.[b]	y, in.[a]	radius r, in.
14	15	32.11	0	122.65
15	-2.5	-5.35	-0.693	122.56
16	-1	-2.14	0.693	122.56
17	-1	-2.14	-0.693	122.56
18(O)-19(C)	0	0	-0.693	122.56
20	1	2.14	-0.693	122.56
21	2.5	5.35	-0.693	122.56
22	10	21.39	0.693	122.56
23(O)-24(C)	0	0	0.625	118.05
25	-20	-41.14	0.625	117.85
26	-15	-30.85	0.625	117.85
27	-10	-20.57	0.625	117.85
28	-5	-10.28	0.625	117.85
29(O)-30(C)	0	0	0.625	117.85
31	10	20.57	0.625	117.85
32-33-34	15	31.49	-.0800	120.32
35-36-37	2.5	5.25	-.0800	120.32
38	0	0	-.0800	120.32
39-40-41	-2.5	-5.25	-.0800	120.32
42-43-44	-15	-31.49	-.0800	120.32
45	10.75	23.01	0	122.65

a. The majority of the strain gages run circumferentially. In the 2-element gages, “C” means “circumferential”, and “O” means “out-of-plane”.

b. See Fig. 4.9 for definition of coordinates.

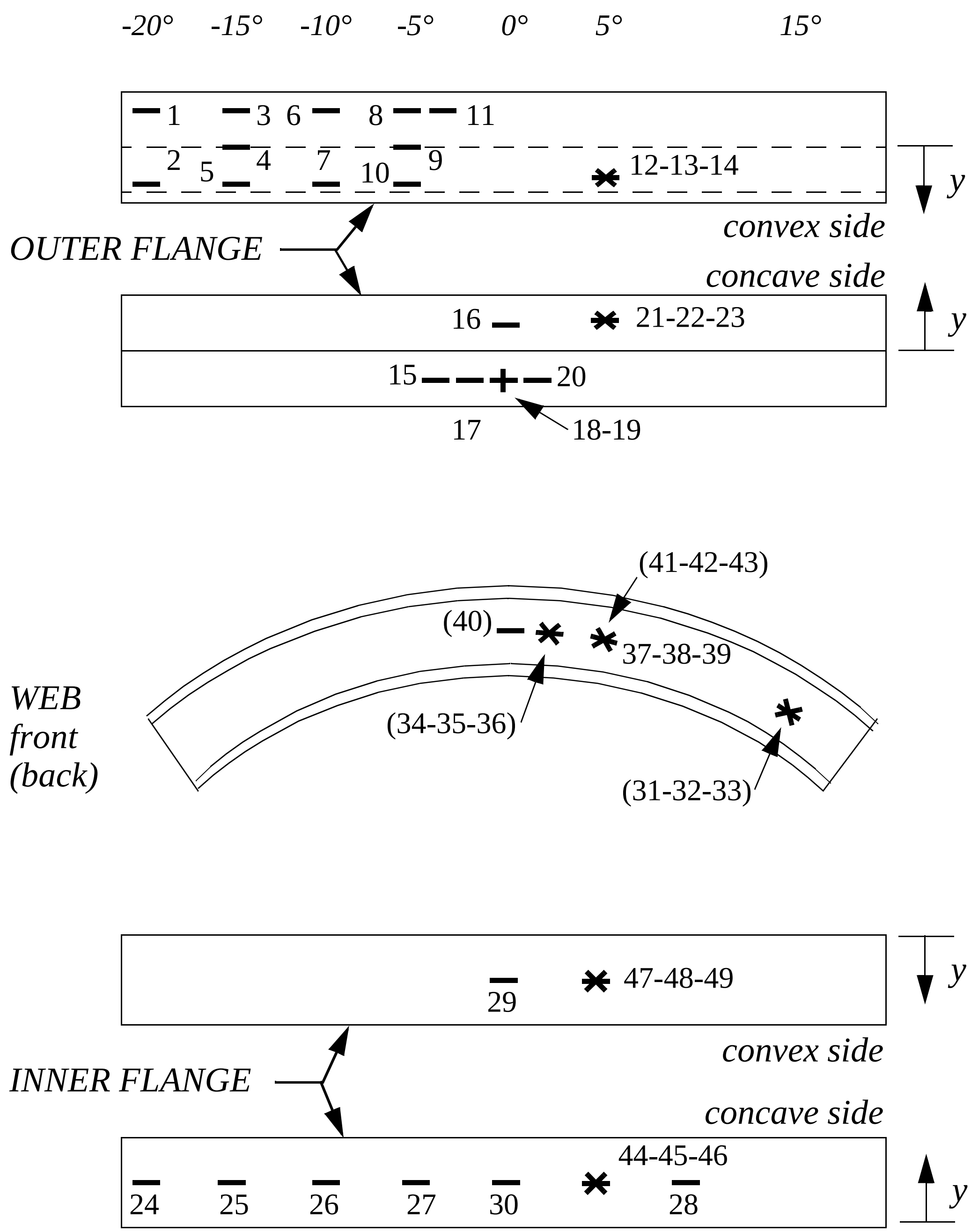

Fig. 4.10 Strain gage lay out on braided composite frame C.

Table 4.4 Circumferential, out-of-plane, and radial locations of strain gages on braided composite frame C.

strain gage #[a]	angle *q*, degrees	*s*, in.[b]	*y*, in.[a]	radius r, in.
1	-20	-43.19	-0.743	123.73
2	-20	-43.19	0.743	123.73
3	-15	-32.39	-0.743	123.73
4	-15	-32.39	0	123.73
5	-15	-32.39	0.743	123.73
6	-10	-21.59	-0.743	123.73
7	-10	-21.59	0.743	123.73
8	-5	-10.80	-0.743	123.73
9	-5	-10.80	0	123.73
10	-5	-10.80	0.743	123.73
11	-2.5	-5.40	-0.743	123.73
12-13-14	5	10.80	0.743	123.73
15	-2.5	-5.40	-0.743	123.64
16	0	0	0.743	123.64
17	-1	-2.16	-0.743	123.64
18(C)-19(O)	0	0	-0.743	123.64
20	1	2.16	-0.743	123.64
21-22-23	5	10.79	0.743	123.64
24	-20	-41.51	0.635	118.92
25	-15	-31.13	0.635	118.92
26	-10	-20.76	0.635	118.92
27	-5	-10.38	0.635	118.92
28	10	20.76	0.635	118.92
29	0	0	0.635	119.12
30	0	0	0.635	118.92
31-32-33	15	31.77	-0.086	121.39
34-35-36	5	10.59	-0.086	121.39

Table 4.4 Circumferential, out-of-plane, and radial locations of strain gages on braided composite frame C.

strain gage #[a]	angle *q*, degrees	*s*, in.[b]	*y*, in.[a]	radius r, in.
37-38-39	5	10.59	+0.086	121.39
40	0	0	-0.086	121.39
41-42-43	1	2.12	-0.086	121.39
44-45-46	5	10.38	0.635	118.92
47-48-49	5	10.40	0.635	119.12

a. The majority of the strain gages run circumferentially. In the 2-element gages, “C” means “circumferential”, and “O” means “out-of-plane”.

b. See Fig. 4.9 for definition of coordinates