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Evaluation of the Behavior of Technova Corporation Rod-Stiffened Stitched Compression Specimens

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Abstract

Under Space Act Agreement 1347 between NASA and Technova Corporation, Technova designed and fabricated two carbon-epoxy crippling specimens and NASA loaded them to failure in axial compression. Each specimen contained a pultruded rod stiffener which was held to the specimen skin with through-the-thickness stitches. One of these specimens was designed to be nominally the same as pultruded rod stitched specimens fabricated by Boeing under previous programs. In the other specimen, the rod was prestressed in a Technova manufacturing process to increase its ability to carry compressive loading. Experimental results demonstrated that the specimen without prestressing carried approximately the same load as the similar Boeing specimens and that the specimen with prestressing carried significantly more load than the specimen without prestressing.

Background

Under Space Act Agreement 1347 between NASA and Technova Corporation, Technova designed and fabricated two carbon-epoxy crippling specimens and NASA loaded them to failure in axial compression. Each specimen contained a single pultruded carbon rod stiffener aligned in the loading direction. Stiffener flanges were stitched to the skin of the specimen so no fasteners were needed.

One specimen was nominally the same as stringer crippling specimens fabricated by Boeing and tested by Boeing and NASA (ref. 1, 2) under the Subsonic Fixed Wing and Environmentally Responsible Aviation Projects. The rod in the second specimen was prestressed during the manufacturing process in an approach developed by Technova (ref. 3). This prestressing was intended to increase the stiffener’s ability to carrying compressive loading.

The pultruded rod stitched concept has been demonstrated to provide excellent structural efficiency in tension and compression based on the NASA and Boeing work. That work served as a starting point and baseline for the Technova work. The prestressing concept, as applied herein, is intended to further increase the structural efficiency of carbon panels that would primarily be loaded in compression throughout their life. The purpose of this document is to describe the results of the NASA tests on the Technova specimens and relate this data to the behavior of Boeing specimens.

Specimen Description and Preparation

The cross section geometry of a pultruded rod stitched crippling specimen is shown in figure 1. The two specimens had nominally the same geometry. Photographs of the Technova specimens are shown in figures 2 and 3. Specimens were approximately 17 inches long and 6 inches wide. Stiffeners were approximately 1.5 inches tall and the skin was approximately 0.12 inches thick. Specimen dimensions are described in Table 1.

Table 1. Specimen Dimensions

	Prestressed	Non-prestressed
Average skin thickness (in.)	0.128	0.117
Skin thickness range (in.)	0.118 to 0.136	0.106 to 0.123
Width (in.)	6.1	5.9
Average stiffener diameter (in.)	0.48	0.48
Length (in.)	16.8	17.0

Both Technova specimens were delivered to NASA with strain gages attached and the ends potted in one inch of an epoxy compound on each loaded end. Ten strain gages were applied to each specimen. All strain gages were axial, with gages on the skin, flanges, stiffener web, and stiffener rod overwrap as shown in the figures 2 and 3.

Prior to testing, the unstiffened side of each specimen was painted with a black and white speckle pattern to allow the use of a digital image correlation (DIC) system during loading to obtain full field displacements and strains of the unstiffened surface**.** A photograph of the prestressed specimen in the test machine is shown in figure 4, where the speckle pattern is visible. Four displacement transducers were used with each specimen. Three displacement transducers were positioned on the crosshead, as shown in figure 4, to monitor the motion of the crosshead so that the uniformity of the shortening could be determined and any rotation of the crosshead could be evaluated. These transducers were located 1 inch in each direction from the corners of the platen, or 11 inches in front of and behind the centerline of the platen and 10.5 inches from the centerline of the stiffener web. The fourth displacement transducer was positioned perpendicular to the stiffener at the midlength position, parallel to the plane of the crosshead. This transducer was used to measure the rolling of the stiffener.

Side supports used to restrict the motion of the unloaded edges were positioned on each unloaded edge 2.5 inches above and below the axial centerline of the specimen, as shown in figure 4. A sketch of these side supports is shown in figure 5, where the slot for the specimen skin is shown. Supports were clamped to the specimen restricting both lateral in-plane motion and out-of-plane motion. Shortening should not have been restricted by the side supports. The nuts on the supports were tightened “finger tight.” The specimen skin thickness was within 0.03 inches of the slot thickness, so only a very small amount of local deformation out-of-plane could occur. Because of the contact between the supports and the specimen skin included approximately 0.2 inches from the edge of the specimen, this condition resembled a clamped edge. In the vertical direction gaps were allowed between the support and the potting at each end of the specimen to allow the specimen to shorten without loading the supports.

Experimental Process

Each specimen was loaded in compression at a rate of 0.008 inches of shortening per minute. For both specimens, strain gage and displacement measurements were recorded five times per second during loading. Digital image correlation images were recorded once each second.

Experimental Results

The displacements measured by all four transducers are shown in figures 6 and 7, respectively, for the non-prestressed and prestressed specimens. The shortening results are shown as the red, blue and green curves and the lateral motion is shown as the black curve.

For both specimens, the displacement transducers measuring shortening showed significant nonlinearity in the load-shortening curves for loading less than approximately 15,000 lb. However, for loading greater than 15,000 lb, the load-shortening relationship is linear. This initial nonlinearity is believed to be caused by irregularities in the potting and load introduction. The three shortening measurements were initially almost identical and remained within approximately 10% of each other throughout the test. For both specimens, some motion of the stiffener occurred but that motion does not appear to indicate stiffener rolling since it remained very gradual motion and never exceeded 0.02 inches for the non-prestressed specimen and 0.01 inches for the prestressed specimen.

Digital image correlation full-field out-of-plane displacement results are shown in figures 8 and 9, respectively, for the non-prestressed and prestressed specimens. White regions within the images are locations where data could not be obtained because of hardware between the camera and the specimen surface such as restraints, clamps, and strain gage wires. Anything attached to the surface or in the field of view of either camera, or casting a shadow on the test article, can limit the area for which DIC data can be reliably collected. Load levels of approximately 500, 10,000, 12,100, 41,000, and 44,000 lb for the non-prestressed specimen are shown. Load levels of approximately 500, 5,000, 15,000, 61,000, and 65,000 lb are shown for the prestressed specimen.

Full-field axial strain results are shown in figures 10 and 11, respectively, for the non-prestressed and prestressed specimen for load levels immediately prior to failure. Specifically, load levels of approximately 44,300 lb for the non-prestressed specimen and approximately 65,000 lb for the prestressed specimen are shown. Again, white regions within the images are locations where data could not be obtained because of hardware between the camera and the specimen surface such as restraints, clamps, and strain gage wires. Isolated peaks in the strains immediately adjacent to the white areas are also inaccuracies based on the obstructed areas. Surface strains in the skin on the unstiffened side did not exceed a compressive strain of 0.006 in/in., indicating that failure did not initiate due to excessive strain in the skin.

The maximum load for the non-prestressed specimen was 44,339 lb. Failure occurred through the skin and stiffener near the potting, as shown in figure 12. The maximum recorded load for the prestressed specimen was 64,955 lb. Failure occurred through the skin near the potting and through the rod overwrap both near the potting and approximately 3.5 inches away from the top failure, as shown in figure 13.

Comparisons Between Technova and Boeing Specimens

The average of the measured shortening results are shown in figure 14 for a typical Boeing rod-stiffened crippling specimen and both Technova specimens. The Boeing specimen was geometrically similar to the Technova specimen with a width of 6.0 inches, a stiffener diameter of 0.48 inches and a length of 18 inches. The Boeing specimens were assumed to be nominally the same as non-prestressed Technova specimen. The skin of the Boeing specimens was 0.055 inches thick so the Technova specimens were approximately twice the thickness of the skin of the Boeing specimens.

However, relatively little load would typically be carried through the skin, so this difference is expected to have little influence on the load carryign capbility of the specimens.

The Boeing specimen displayed a more linear load-shortening behavior than the equivalent Technova specimen, but the maximum load values were similar. Two pristine Boeing crippling specimens and two fatigued Boeing crippling specimens (ref. 3) have been tested with the failure loads shown in Table 2, resulting in an average failure load of 45,638 lb. The Technova non-prestressed specimen failed at a load level typical of the Boeing specimens.

Table 2. Failure Loads

Specimen ID	Manufacturer	Test type	Failure load (lb)
Rod 1*	Boeing	Static	48,500
Rod 2*	Boeing	Static	41,400
R3*	Boeing	Fatigue/static	45,000
R4*	Boeing	Fatigue/static	47,654
Non-prestressed	Technova	Static	44,339
Prestressed	Technova	Static	64,994

*Reference 3

The failure load of the prestressed Technova specimen was significantly greater than that of the non-prestressed specimens. Comparing the prestressed specimen to the average of the Boeing specimens or to the Technova non-prestressed specimen, the prestressed specimen supported over 40 percent more load than specimens without prestressing, as shown in figure 15. Boeing specimens are represented in the figures as solid green bars and their average is the green hatched bar. Technova specimens are represented by the solid red bars. With only one prestressed specimen, definitive conclusions cannot be drawn, however, the prestressing appears to have a significant impact on the load-carrying ability of the specimen.

Concluding Remarks

Two carbon-epoxy pultruded rod stitched specimens fabricated by Technova Corporation were loaded to failure in axial compression at NASA Langley Research Center. The loads supported by the Technova specimens indicate that the Technova specimens are of high quality. The non-prestressed specimen supported a load level equivalent to comparable Boeing specimens. The difference in load-carrying capability between the prestressed and non-prestressed specimens indicates that the prestressing technique has a potential to improve the structural efficiency in selected structures. Since most aircraft structures are not loaded exclusively in one direction, prestressing is not appropriate everywhere, however, selective application of this technique could be warranted for aircraft, launch vehicle or other structures.

References

1. Velicki, A., “Damage Arresting Composites for Shaped Vehicles,” NASA CR-2009-21532, Sep. 2009.
2. Jegley, Dawn C., “Experimental Behavior of Fatigued Single Stiffener PRSEUS Specimens, NASA TM 2009-215955, Dec. 2009.
3. Technova Corporation, “Prestressing of Composite Structures for Enhanced Efficiency,” Phase II SBIR, U.S. Air Force contract FA8650-09-C-3908.

Figures

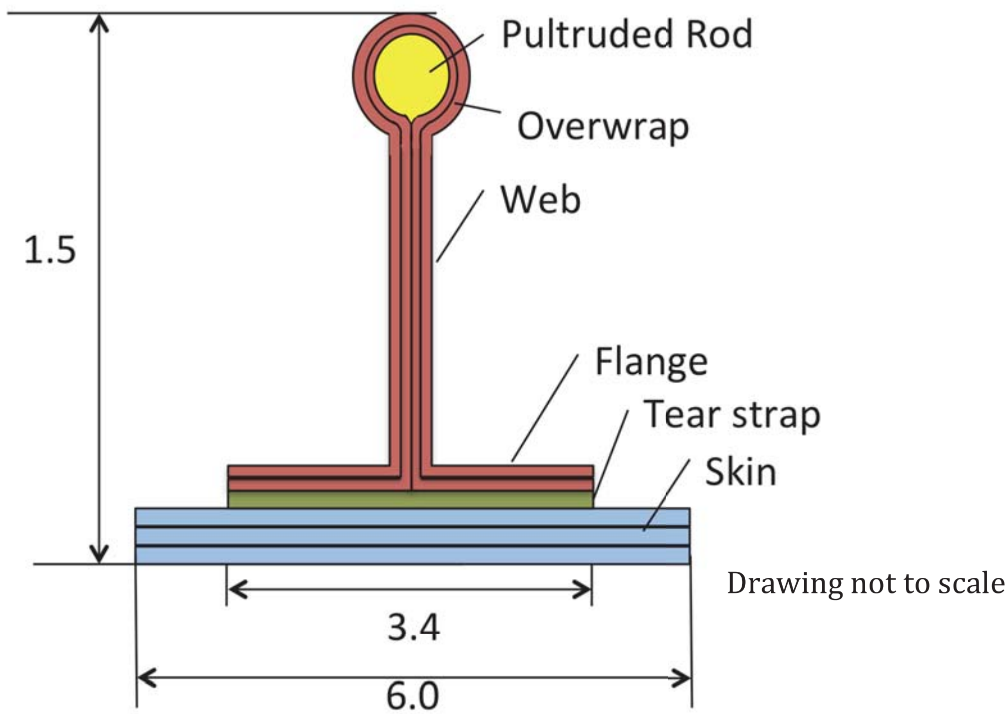
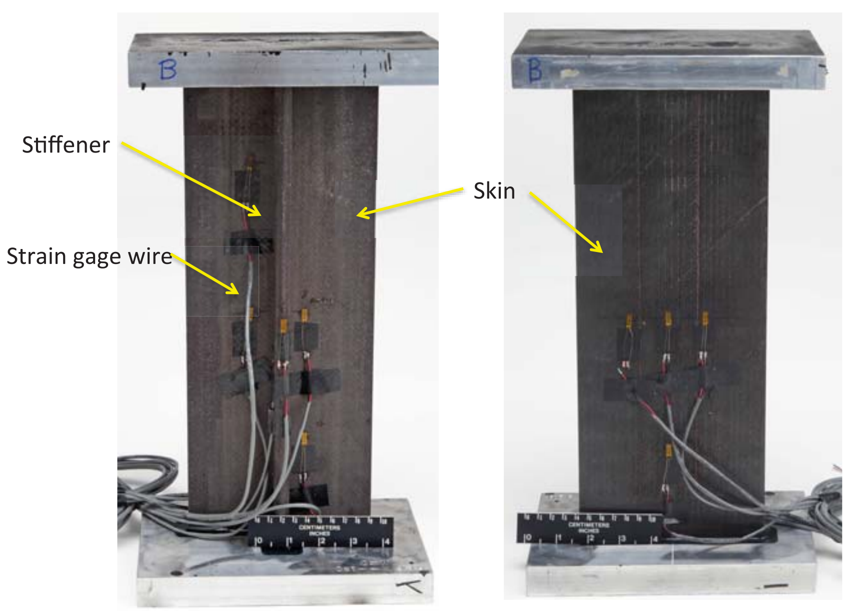
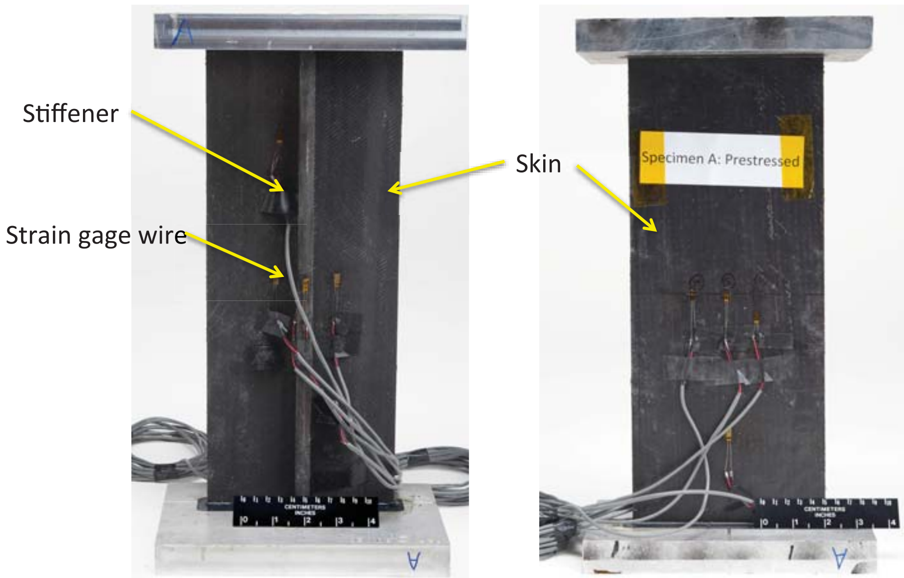


Fig. 1. Cross section geometry. Dimensions are in inches.



a) Stiffened side b) Unstiffened side

Fig. 2. Technova non-prestressed specimen.



a) Stiffened side b) Unstiffened side

Fig. 3. Technova prestressed specimen.

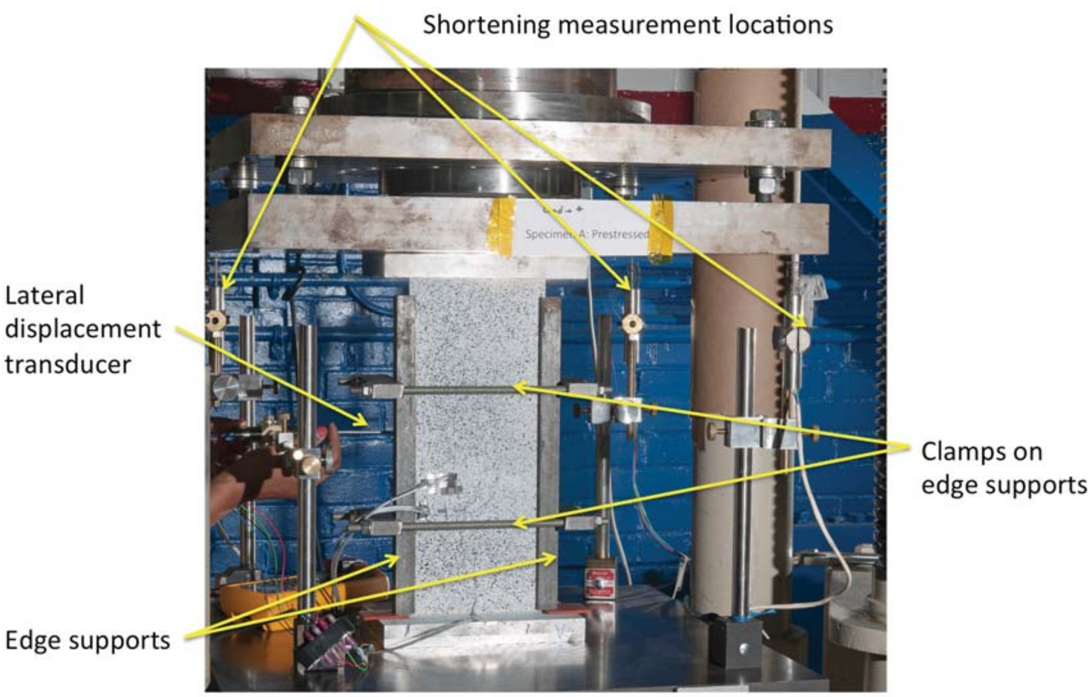


Fig. 4. Specimen in test machine and displacement measurement locations.

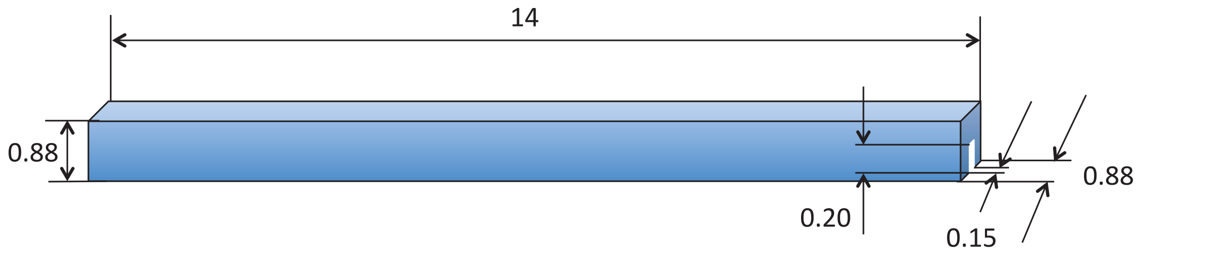


Fig. 5. Edge supports. Dimensions are in inches.

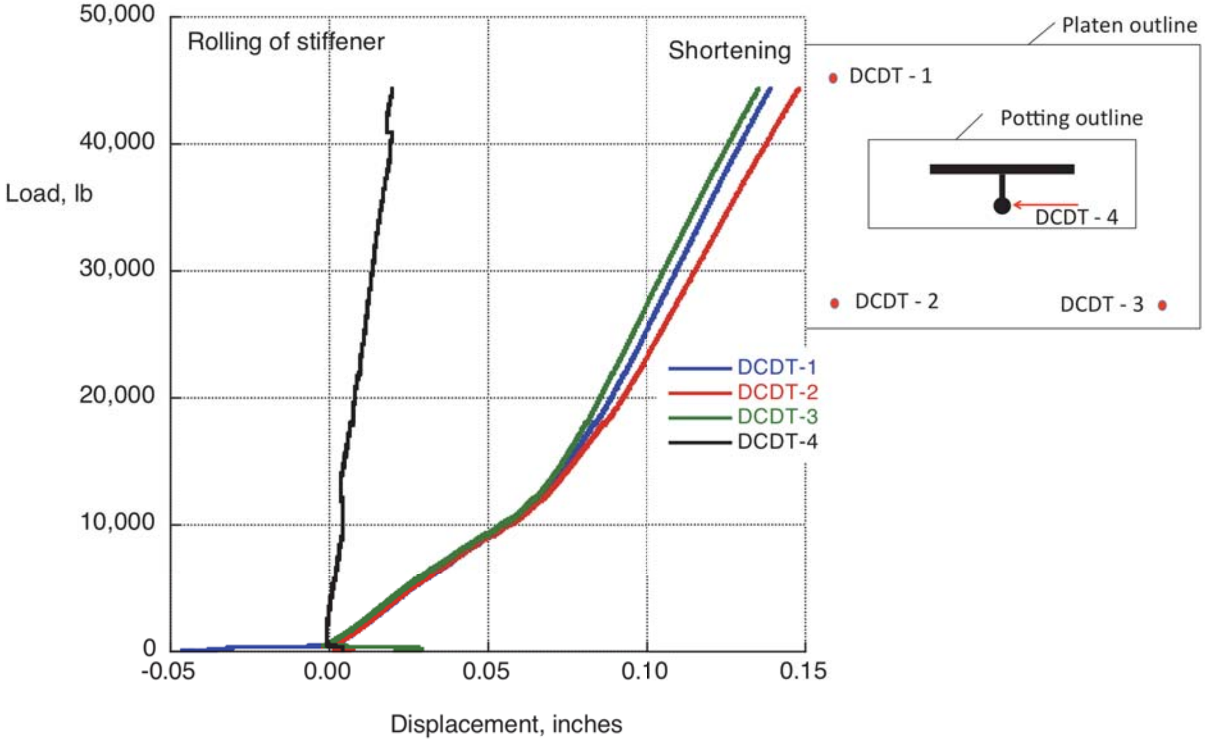


Fig. 6. Displacement transducer measurements for Technova non-prestressed specimen.

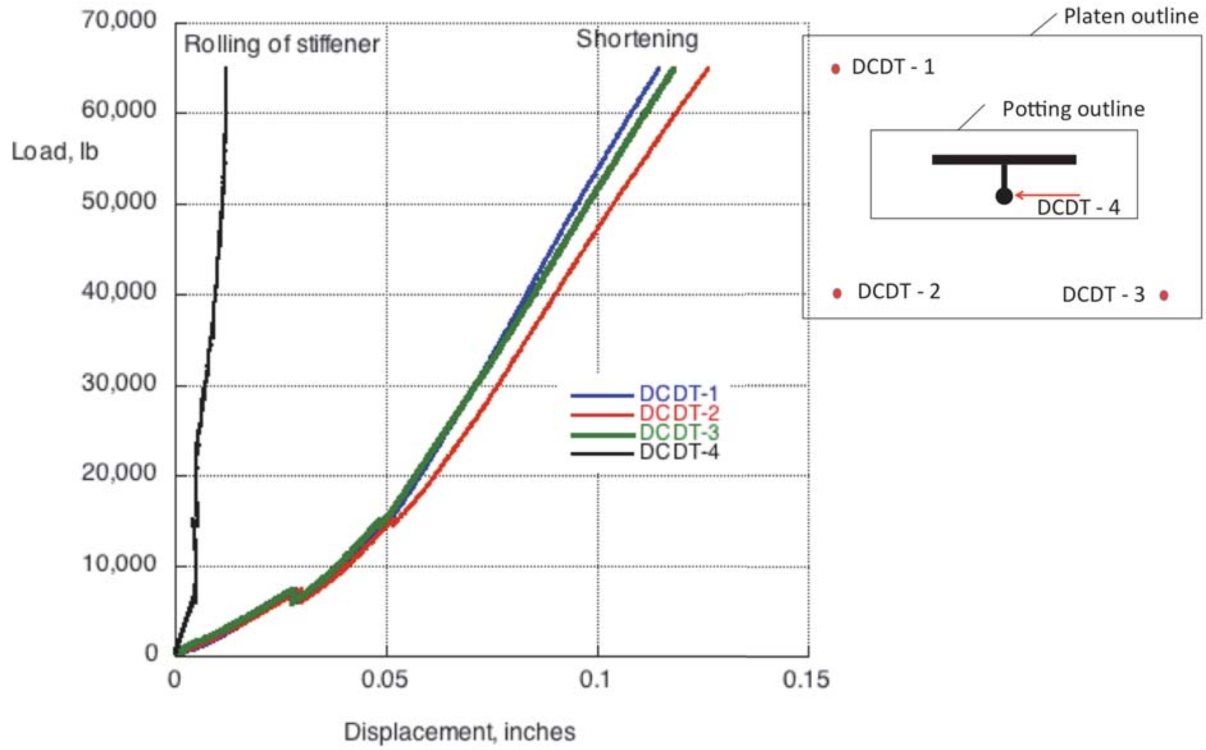
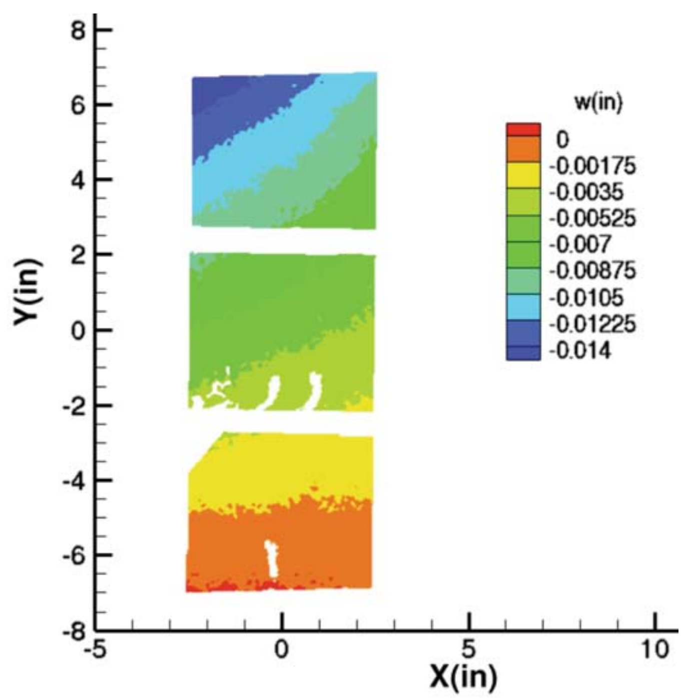
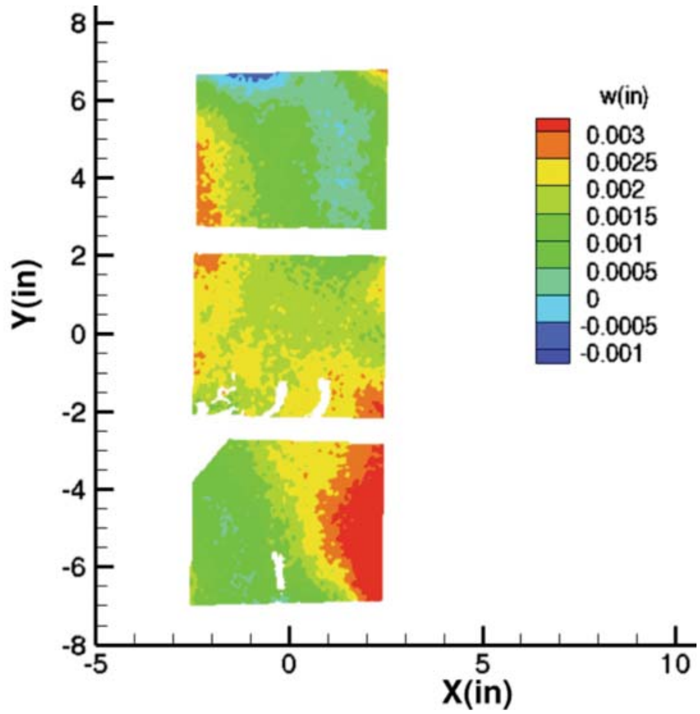


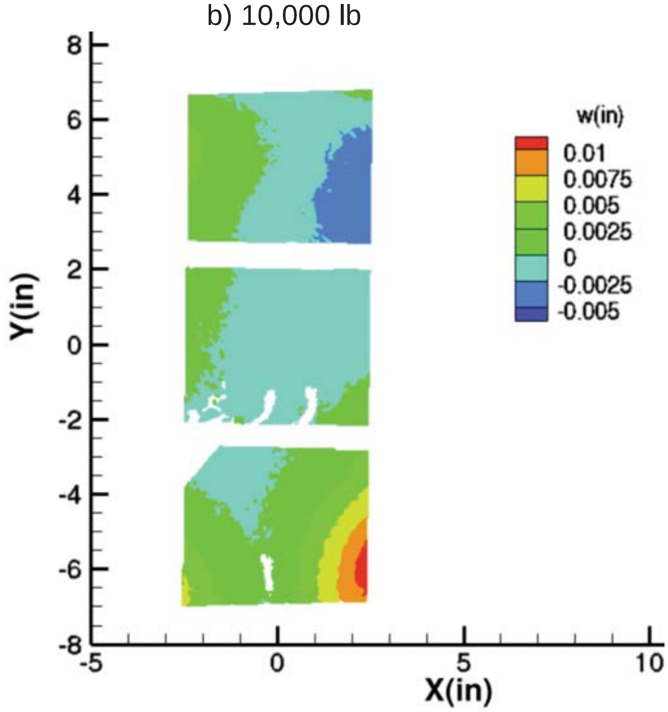
Fig. 7. Displacement transducer measurements for Technova prestressed specimen.



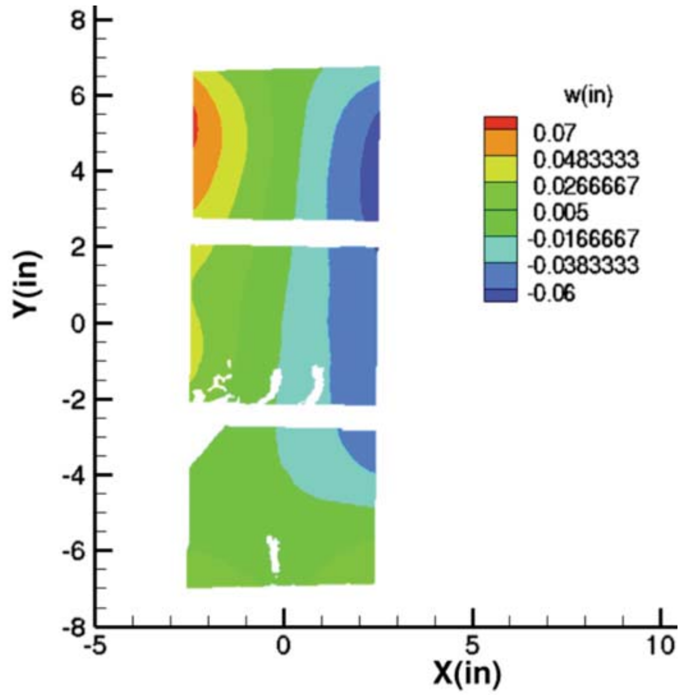
a) 500 lb
Fig. 8. Full-field displacements for Technova non-prestressed specimen.



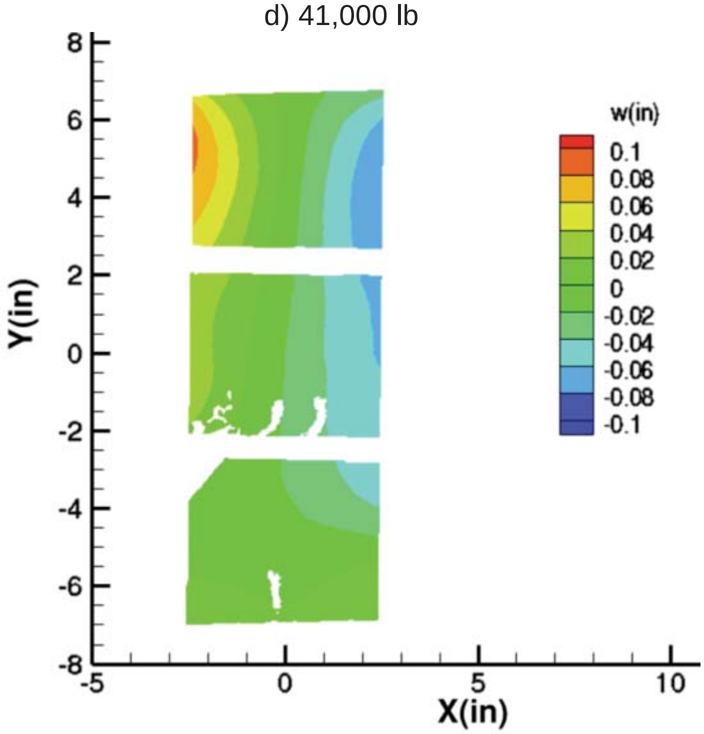
b) 10,000 lb



c) 12,100 lb
Fig. 8. Continued.

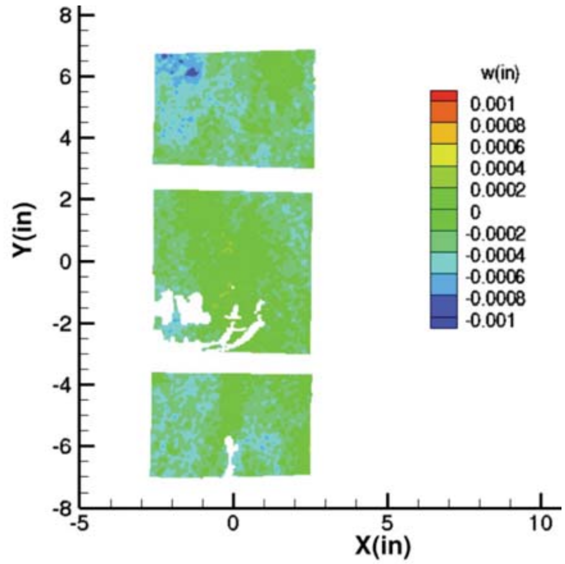


d) 41,000 lb

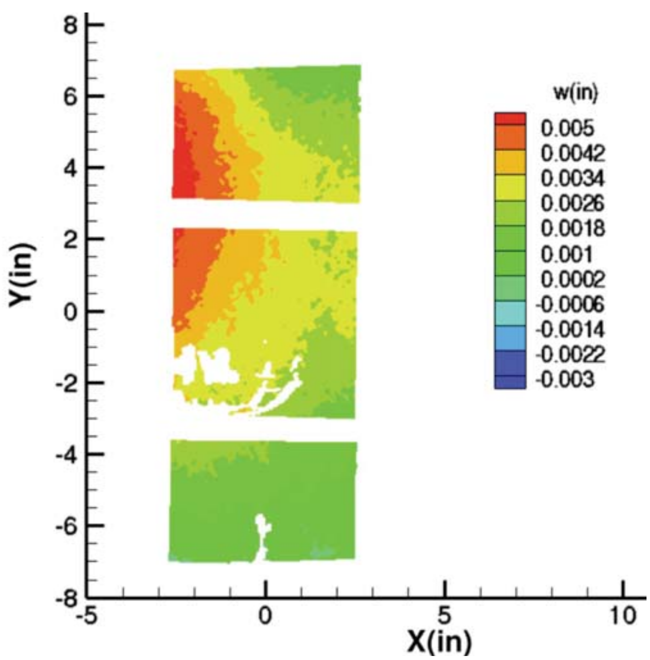


e) 44,300 lb

Fig. 8. Concluded

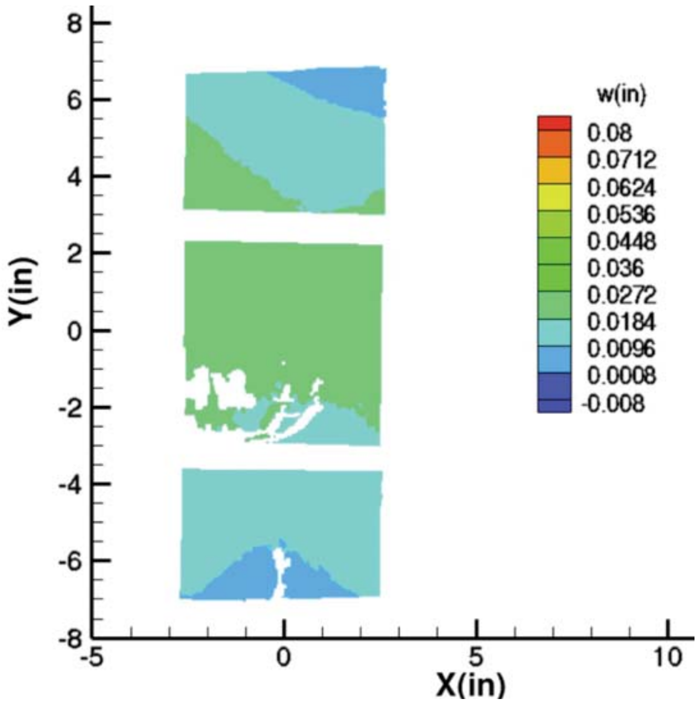


a) 500 lb

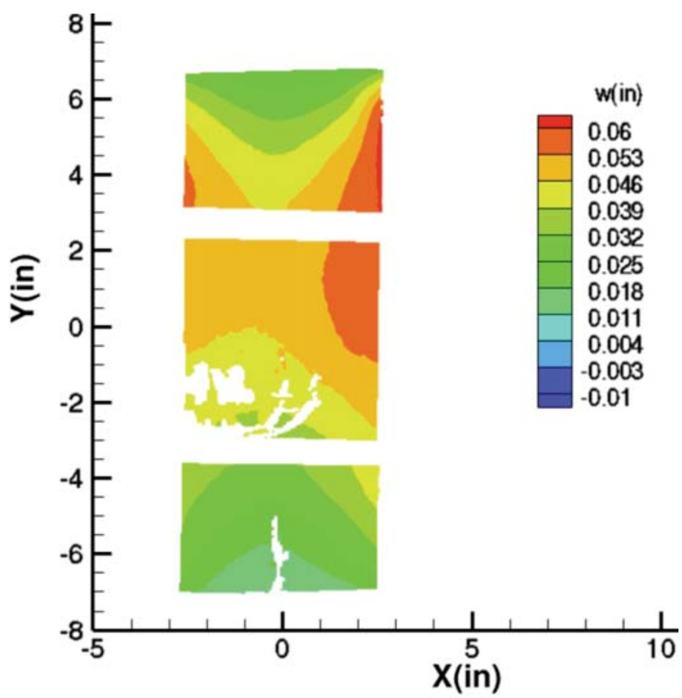


b) 5,000 lb

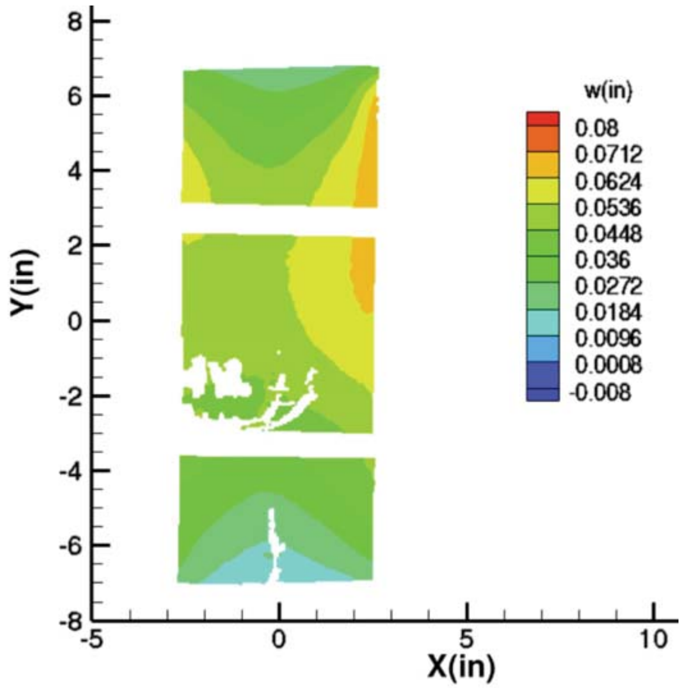
Fig. 9. Full-field displacements for Technova prestressed specimen.



c) 15,000 lb



d) 61,000 lb
Fig. 9. Continued.



e) 65,000 lb

Fig. 9. Concluded.

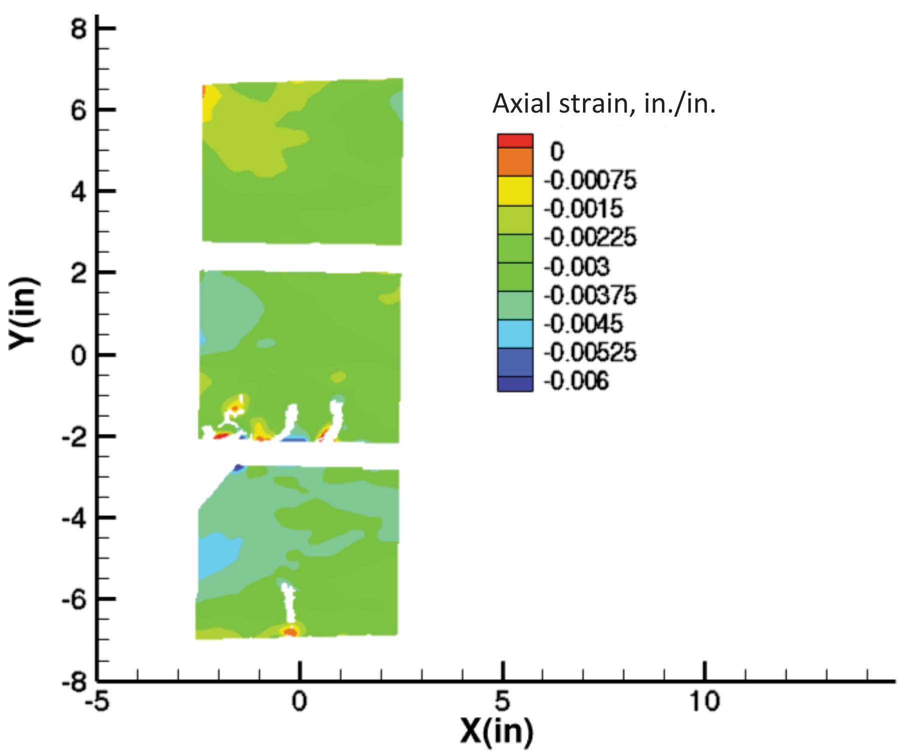
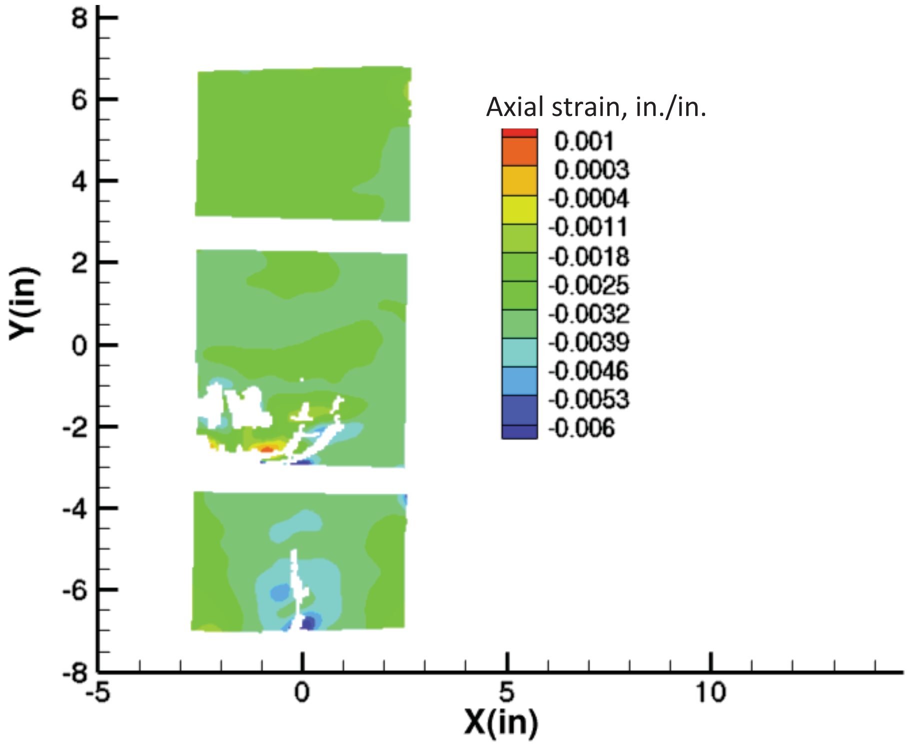
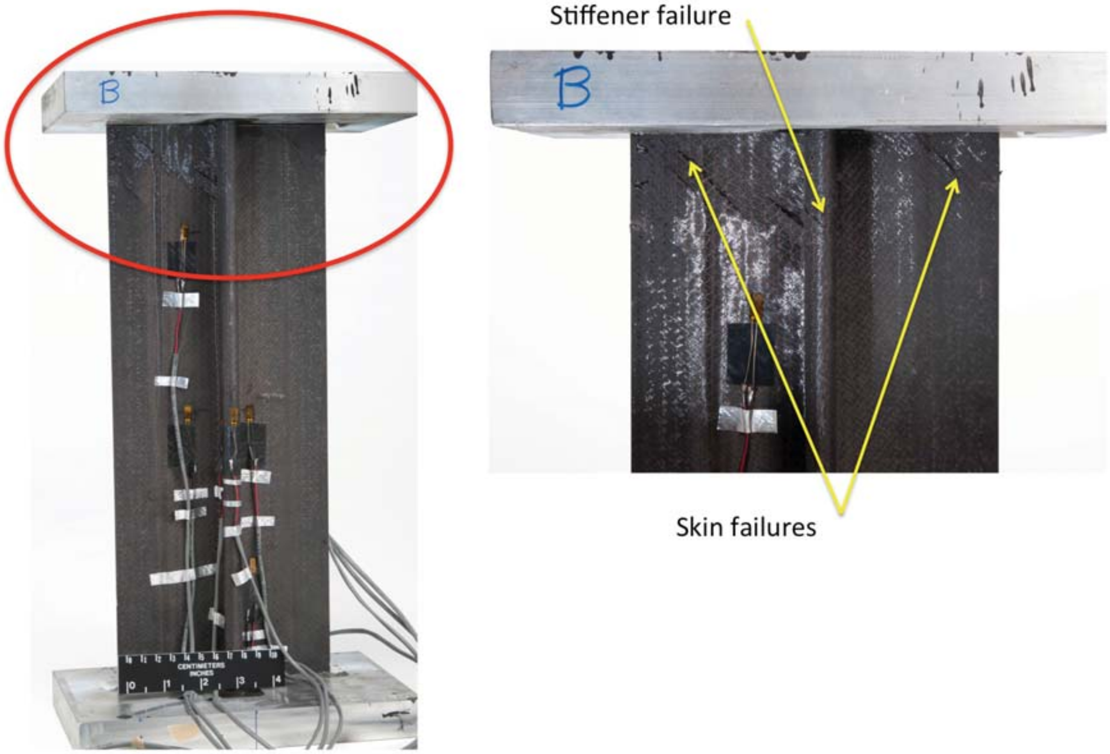


Fig. 10. Full-field strains for non-prestressed specimen at 44,300 lb.

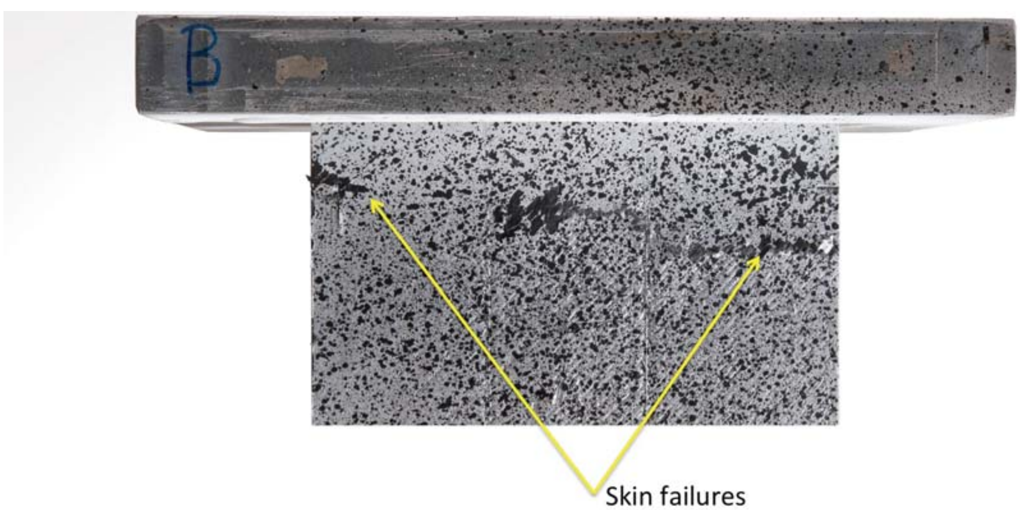


b) 65,000 lb

Fig. 11. Full-field strains for Technova prestressed specimen.

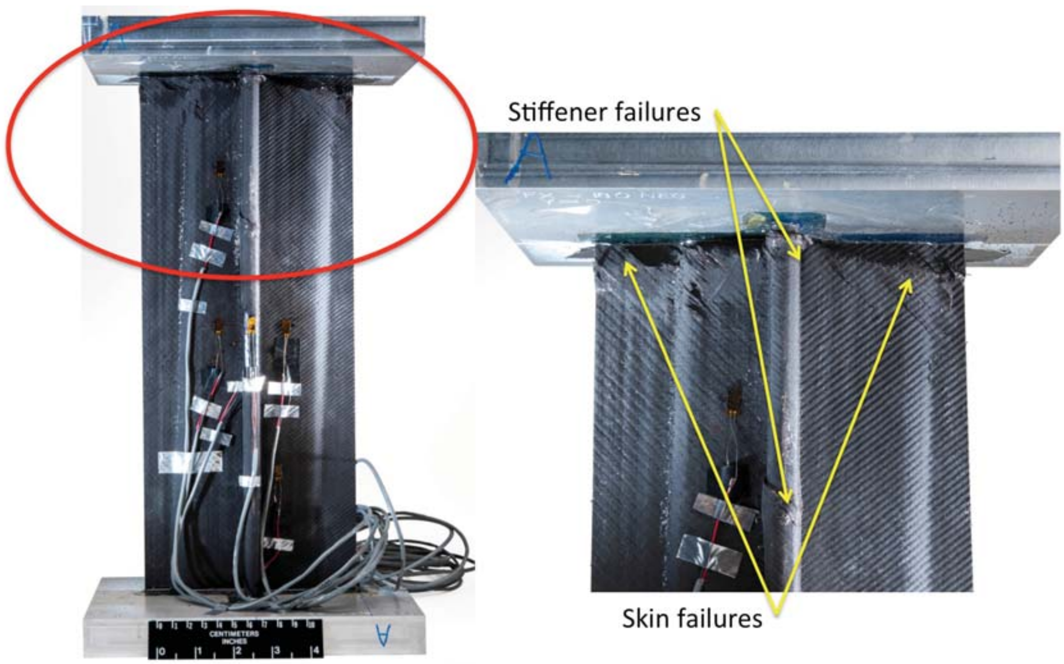


a) Stiffened side



b) Unstiffened side

Fig. 12. Post-test photographs of Technova non-prestressed specimen.



a) Stiffened side

b) Unstiffened side

Fig. 13. Post-test photographs of Technova prestressed specimen.

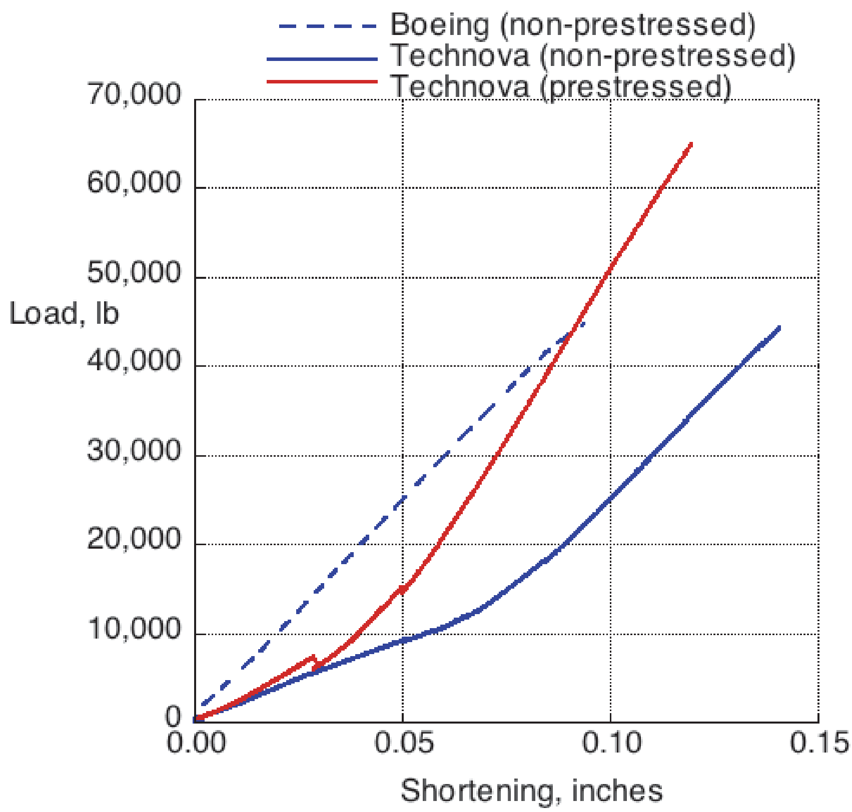


Fig. 14. Load-shortening comparison with Boeing specimen.

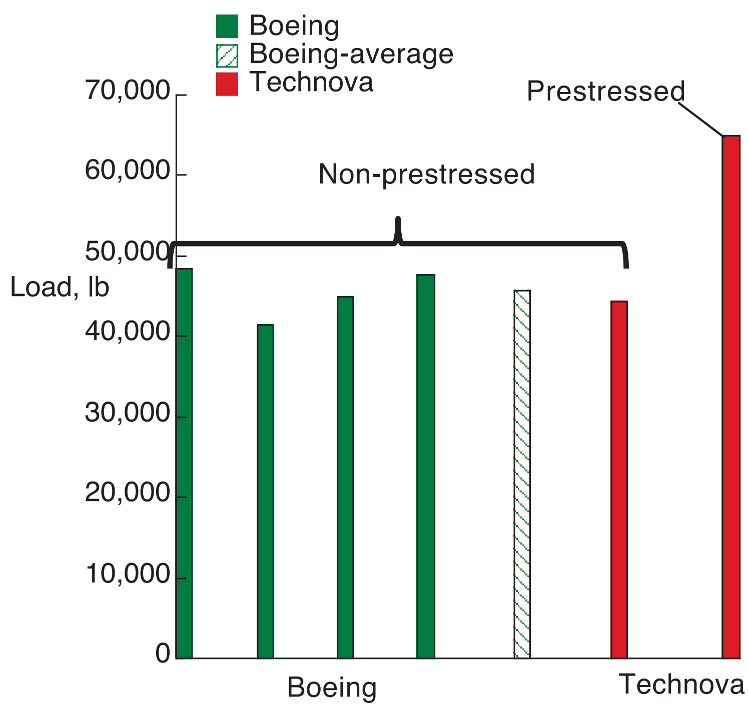


Fig. 15. Failure load comparison with Boeing specimens.

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14. ABSTRACT

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15. SUBJECT TERMS

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