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"Evaluation of Chest Band Responses in a Dynamic Test Environment"

Alena V. Hagedorn, Research Engineer

Ronald W. Burton, Engineering Technician

Transportation Research Center, Inc.

East Liberty, OH

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INTRODUCTION

Measurement of the human torso, in terms of its crush profile while being subjected to an impact event is critical to the understanding of collision related injuries. Previously, trauma research relied primarily on accelerometers, load cells, and high speed photography for the examination of impact dynamics. The External Peripheral Instrument for Deformation Measurement (EPIDM), commonly called the chest band, is an instrument that allows trauma investigators to quantify distortion to a given body region. The device consists of forty strain gages spaced approximately 25 mm apart, mounted on a thin piece of steel, and enclosed in a urethane coating. When wrapped around a deformable body, the band offers curvature data at each of the active strain gage locations. The curvature data can be used to provide geometrical descriptions of the cross-sectional contour of the deformable body as a function of time. A more comprehensive description of the chest band can be found in reference #1. The following text is an evaluation of chest band responses in a dynamic test environment.

BACKGROUND

A series of tests was conducted using the Hybrid III thorax with two chest bands, one wrapped externally over the thorax jacket and the other wrapped directly over the ribs, under the jacket. The intent of this study was to monitor both internal and external chest bands and compare their outputs to film images for confirmation of the chest band's accuracy in measuring a deflection event.

The test series involved pendulum impacts to the thorax at various velocities and orientations, using the two impact surfaces. The specifics of these tests are discussed in the following text.

GENERAL TEST SETUP

The tests were performed with the Hybrid III thorax removed from the dummy and placed in a fixture (Figure 1). The fixture holds the thorax in place with attachments at both the top and bottom of the spine box. Rotation of the thorax about this axis is then possible so that the thoracic impacts can be obtained at any desired impact angle.

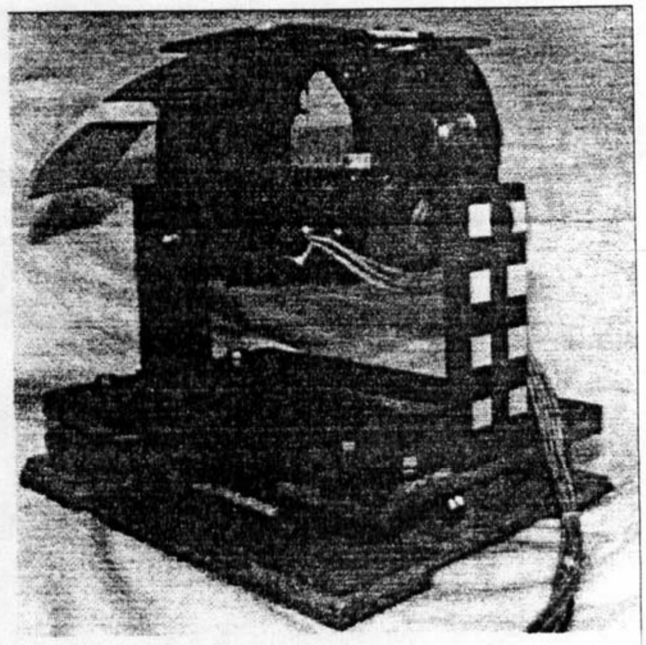

Figure 1 -- Test fixture for holding thorax during testing

Two different impactor heads were used in the dynamic tests. One impactor head was fabricated from 2.54 cm (1") thick aluminum cut into a 20.3 cm (8") diameter circle. The edges were rounded with 2.54 cm curvature (Figure 2). The result was a flat 15.24 cm (6") diameter circular area with a 2.54 cm rounded edge. This impactor is similar to the impactor face used for thoracic calibration tests which is a round 15.24 cm diameter face with a 0.64 cm (0.25") rounded edge. The edge has been rounded more to avoid localized contour changes.

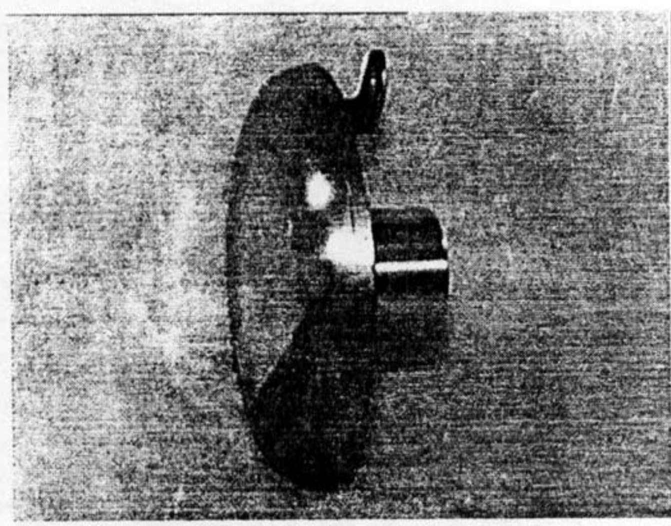

Figure 2 -- Compression head used for quasi-static and impact tests.

The second impactor face simulated a shoulder belt during sled tests using a three-point belted Hybrid III dummy and a chest band. A contour from this chest band at maximum deflection showed approximately a 2.54 cm radius of curvature attributed to the seatbelt contact. Therefore, the impactor face was designed to impose a 2.54 cm radius of curvature to mimic the response seen in the sled tests and simulate a loaded belt imprint on the chest. A 17.8 cm (7") long, 2.54 cm radius cylinder was fabricated from aluminum. The cylinder was then cut lengthwise through the center (Figure 3). The length was chosen as 17.8 cm to provide similar deflections to both the upper and lower sternum when the impactor was centered along the midsagittal line directly over the sternum.

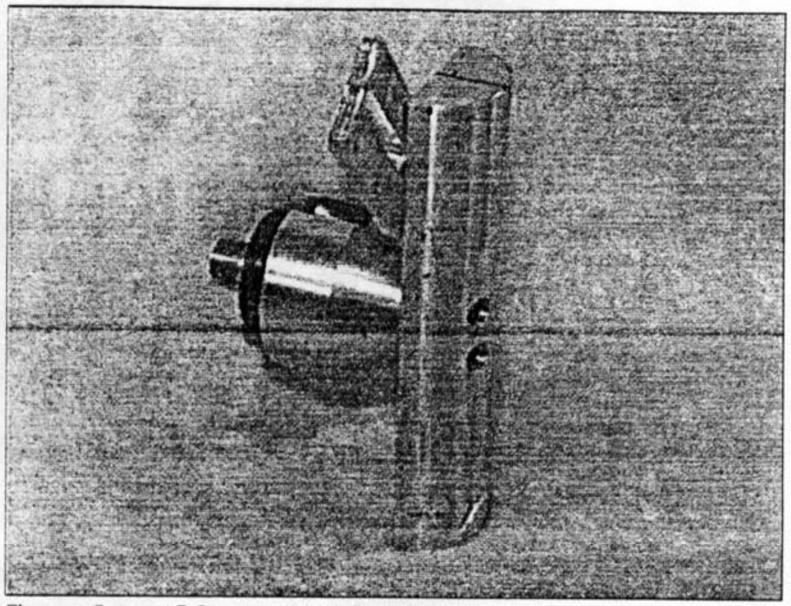

Figure 3 -- 17.8 cm Long, 2.54 cm Radius Compression Head

Chest bands were wrapped both internally and externally around the thorax jacket over the sixth rib. This location was chosen since a cross sectional view of the chest bands from the bottom of the thorax could easily be observed with the high speed video camera. RTV compound, such as that used for electronics applications, was applied over the sternum plate to smooth out the area between and over the boltheads located on the sternum plate. This was intended to reduce erroneous chest band gage readings from abrupt changes in contour which may bias the output shape calculated via the chest band data.

The thorax was positioned for dynamic impacts using a linear pendulum impactor (Figure 4). A variety of velocities and test configurations were utilized. Table 1 lists the test conditions for the ten types of impact tests. The 0° position of the thorax indicates that the impact was straight into the thorax at the mid sternum. For Tests 66-72, the thorax was rotated 20° or 30° down on the dummy's right side about the z axis. The impact head was positioned with the line of impact directed through the center of the sternum. This configuration allowed the thorax to experience lateral movement, and thus determine the ability of the chest band to monitor this type of deflection.

TEST RESULTS

The results for three tests are presented in detail. In addition, error sources from several other tests are included for comparison (Table 2). The edges of the internal and external EPIDM's were painted for visibility in the high speed video, and appear as the white contours (externally over the thorax jacket and internally directly over the

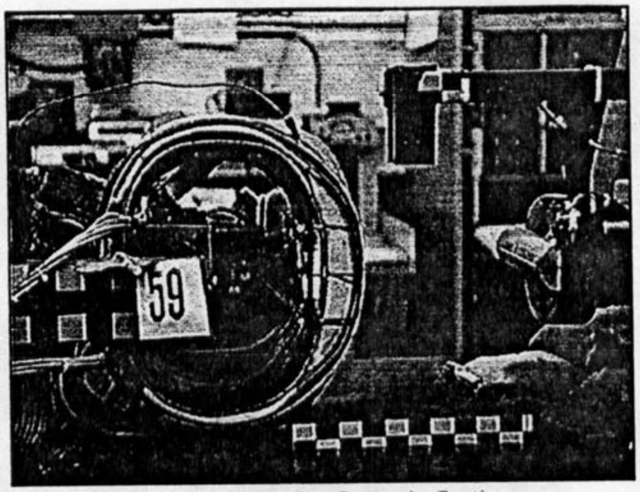

Figure 4-- Thorax Setup for Dynamic Testing

TABLE 1. Impact Test Conditions

Test Number	Velocity (m/s)	Type of Compression Head	Thorax Angle	Position of Thorax Compression
46	3.5	20.3 cm diameter circle with 2.54 cm rounded edge	0°	Centered between ribs 5 and 6
48	4.1	20.3 cm diameter circle with 2.54 cm rounded edge	0°	Centered between ribs 5 and 6
50	5.2	20.3 cm diameter circle with 2.54 cm rounded edge	0°	Centered between ribs 5 and 6
55	3.5	17.8 cm long, 2.54 cm radius cylinder	0°	Mid sternum
59	4.2	17.8 cm long, 2.54 cm radius cylinder	0°	Mid sternum
61	4.8	17.8 cm long, 2.54 cm radius cylinder	0°	Mid sternum
66	3.5	17.8 cm long, 2.54 cm radius cylinder	20° down on right side	Mid sternum
68	3.5	17.8 cm long, 2.54 cm radius cylinder	30° down on right side	Mid sternum
70	4.2	17.8 cm long, 2.54 cm radius cylinder	20° down on right side	Mid sternum
72	4.2	17.8 cm long, 2.54 cm radius cylinder	30° down on right side	Mid sternum

TABLE 2. Differences between video images and chest band produced overlays

Test Type	Test Configuration	Test Number	Time	Band	Maximum Difference Between Video Image and Band Overlay (mm)
Impact	flat, circular impactor 0° impact angle 4.1 m/s	48	21 msec	Internal	7.5
			33 msec		10.0
	flat, circular impactor 0° impact angle 5.2 m/s	50	21 msec	Internal	10.0
				External	10.0
			33 msec	Internal	20.0
				External	10.0
	cylindrical impactor 0° impact angle 3.5 m/s	59	37 msec	Internal	7.5
	cylindrical impactor 0° impact angle 4.8 m/s	61	21 msec	Internal	7.5
	clylindrical impactor 20° impact angle 4.2 m/s	70	32 msec	Internal	10.0
			42 msec		12.5

ribs) in Figures 5 – 12. The EPIDM graphical data are presented as a series of points (squares) for each gage location, connected by a solid line. The chest band contours generated from the band data were overlaid on video images at specific time intervals for comparison with both chest bands. The video prints were scaled to match the plots using the first time frame (t=0) and subsequent frames were scaled accordingly. The plots were placed over the video prints and arranged until the best fit between the plot and the video image was obtained. Some error in fit may be introduced by slight differences in scaling between the plots and the video print. Figures 5 – 8 show overlays of the chest contours produced from the external and internal chest band data for Test 55. This view is from the bottom of the thorax, thus the dummy's right side is to the top in the figure. This test illustrates the capability of both the internal and external chest bands to reproduce a 3.5 m/s impact with the cylindrical impactor. The next two tests (50 and 70) (Figures 9–12) show impact situations in which the band produces some error when compared to the video image.

DISCUSSION

Table 2 quantifies the tests that produced differences between the plots generated from the chest band's electronic data and corresponding video images (Figures 9–12). These values were obtained by measuring the maximum difference between the chest band plot and the chest band as seen in the video. Errors from additional tests are included in Table 2 for informational purposes. Tests not included in this table showed little/no difference between the chest band plots and video images.

Figures 5 –8 display the chest band overlays for Test 55, a 3.5 m/s impact test using the cylindrical impactor. These Figures illustrate the band's capability of effectively reproducing a contour from an impact shape which imposes a severe curvature. Both internal and external bands accurately reproduced the thoracic deformation event.

A total of 32 time intervals were analyzed for the 10 impact tests listed in Table 1. For each test, three or four time intervals were selected at approximately 10 msec intervals, with the last time interval in each test displaying the maximum deflection. The external band displayed a disagreement of 10.0 mm at only two of these time intervals. Both discrepancies took place in Test 50, a 5.2 m/s impact test using the 20.3 cm circular impactor. These results occurred even though the edges of the impactor had been rounded to minimize adverse results due to sharp edges. The internal band plots disagreed in 8 of the 32 time intervals in the impact tests. Discrepancies between 7.5 mm and 20.0 mm were measured.

Table 3 discusses the possible reasons for the discrepancies between the video image and the chest band plots quantified in Table 2 . In several tests, the chest band plots appeared to experience more (concave) curvature than actually occurred (Figures 9–12) (Tests 50 and 70). This may have resulted from "sharp" edges (or a "point" deflection) which impacted the band directly over a gage and caused a large "false" concave curvature. The large curvature then affected the remainder of the contour shape. Conversely, when a chest band plot displayed less deflection than the video image (Figures 9 and 10) (Test 50), a curvature event may have occurred <u>between</u> two adjacent gages which was then undetected by the gages on either side of the impact. The chest band thus "missed" important information regarding the overall shape, and the result was an output contour lacking the true deformation at that point. For these loading conditions, the chest band appeared to indicate less deflection than actually occurred.

Finally, a gage (or gages) experienced excess convex curvature as displayed by the internal band in Test 50 (Figures 9 and 10) due to increased curvatures over the RTV covering the sternum. In previous studies (2) using the chest band wrapped internally, directly over the ribs, it was determined that abrupt changes in contour such as that over screw heads can cause erroneous chest band gage readings and thus bias the output shape calculated via the chest band data. These abrupt contour changes were observed when the chest band was placed over the

Hybrid III sternum boltheads. Two of these bolts secured the ribs to the bib and the other two attached the sternum plate to the bib. Since the spacing between the bolts was approximately 2.5 to 3 cm, this allowed the chest band to deform over the bolts and depress into the 2.5 to 3 cm space when subjected to thoracic loading. This resulted in localized gage readings which biased chest band output. This situation is normally avoided since the chest band is used externally over the thorax jacket of the dummy. Since this project utilized a chest band wrapped internally as well as externally, RTV compound such as that used for electronics applications, was applied over the sternum plate to smooth out the area between and over the boltheads where the chest band was wrapped. The RTV compound was flexible enough to cover the bolts yet did not constrain movement of the rib/sternum interface. In this test series, even with the RTV covering the space between the boltheads, (convex) erroneous gage readings still occurred in the internal band. This could be due to the high velocity of the impact coupled with the large area of

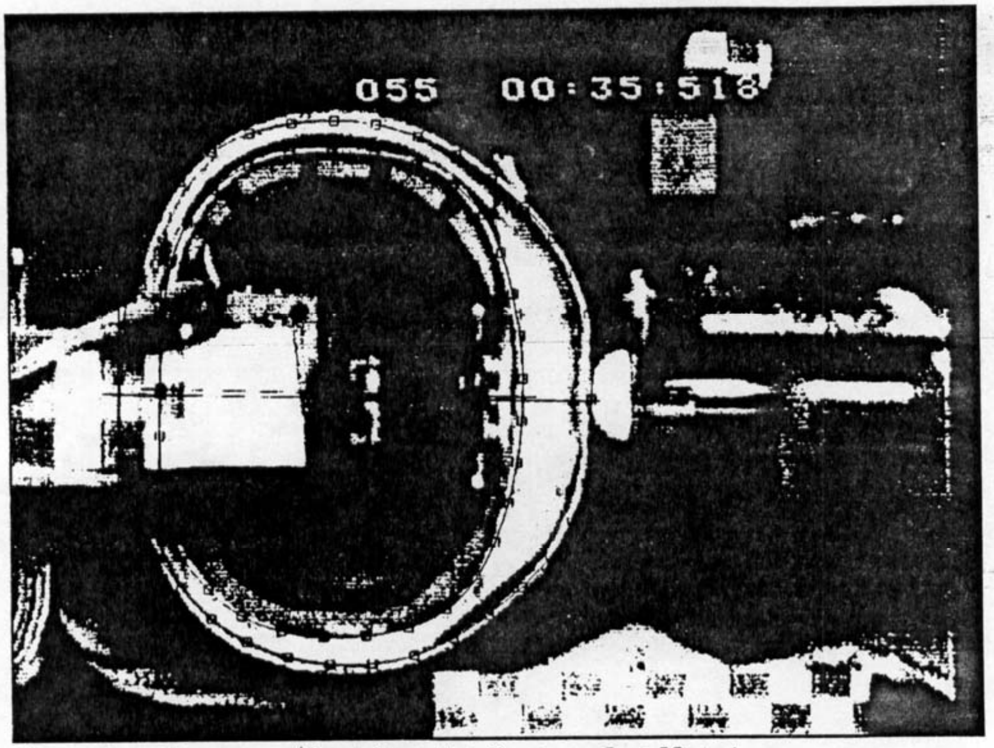

Figure 5-- Video Image/Chest Band Plot Overlay - Test 55, t=1 msec

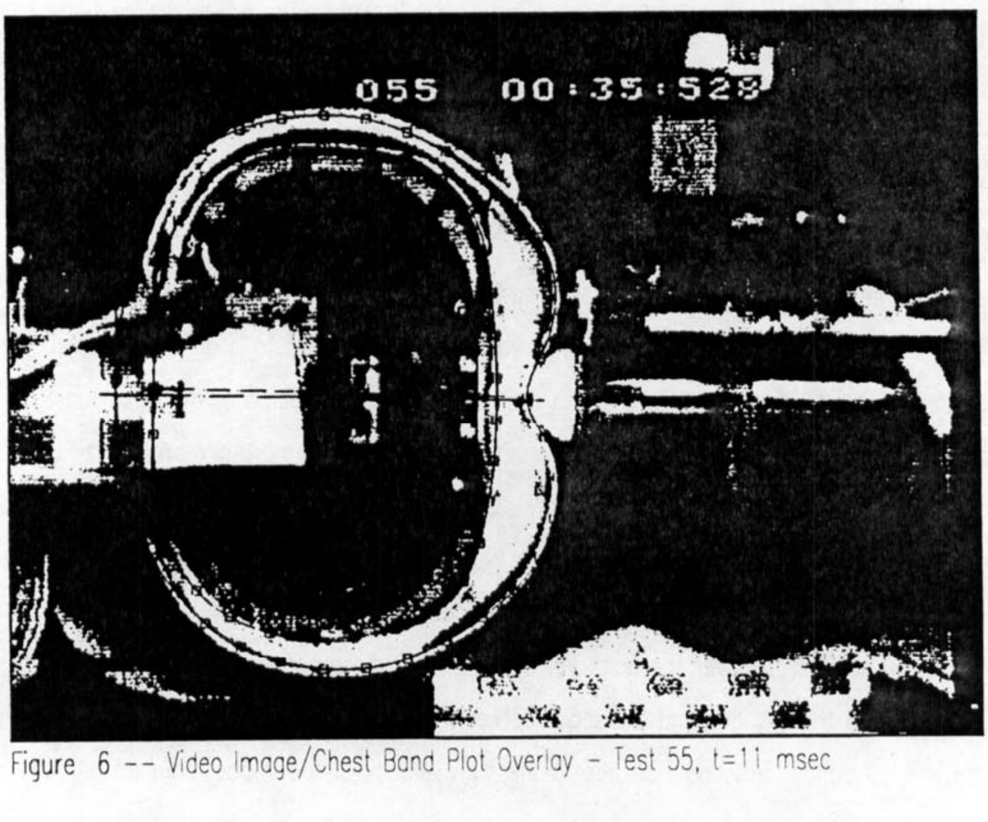

Figure 6 -- Video Image/Chest Band Plot Overlay - Test 55, t=11 msec

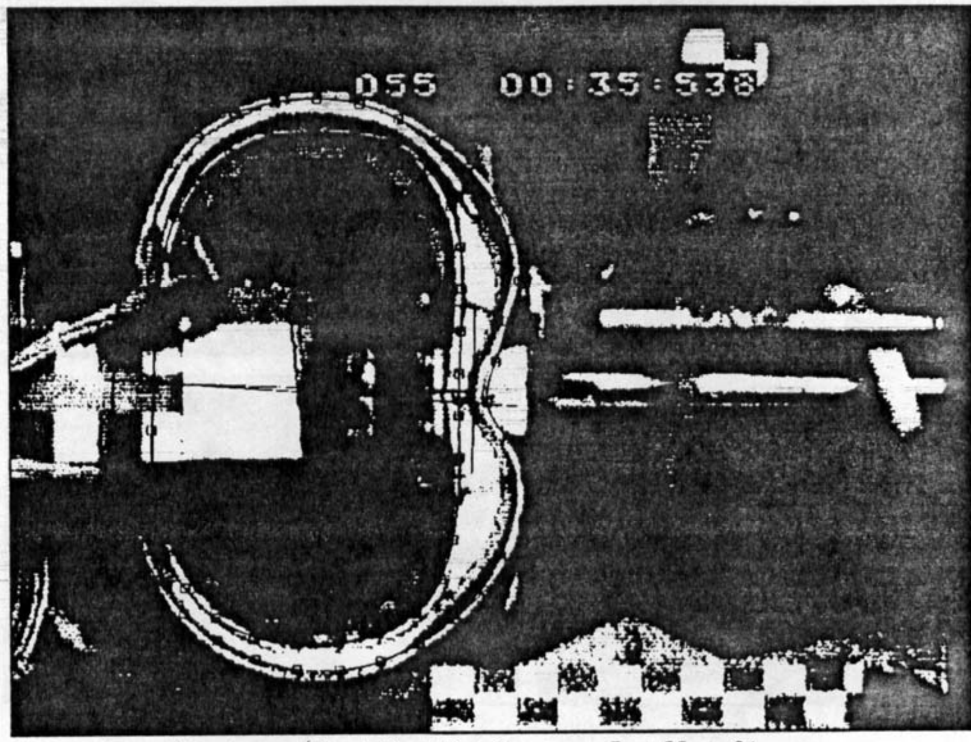

Figure 7 -- Video Image/Chest Band Plot Overlay - Test 55, t=21 sec

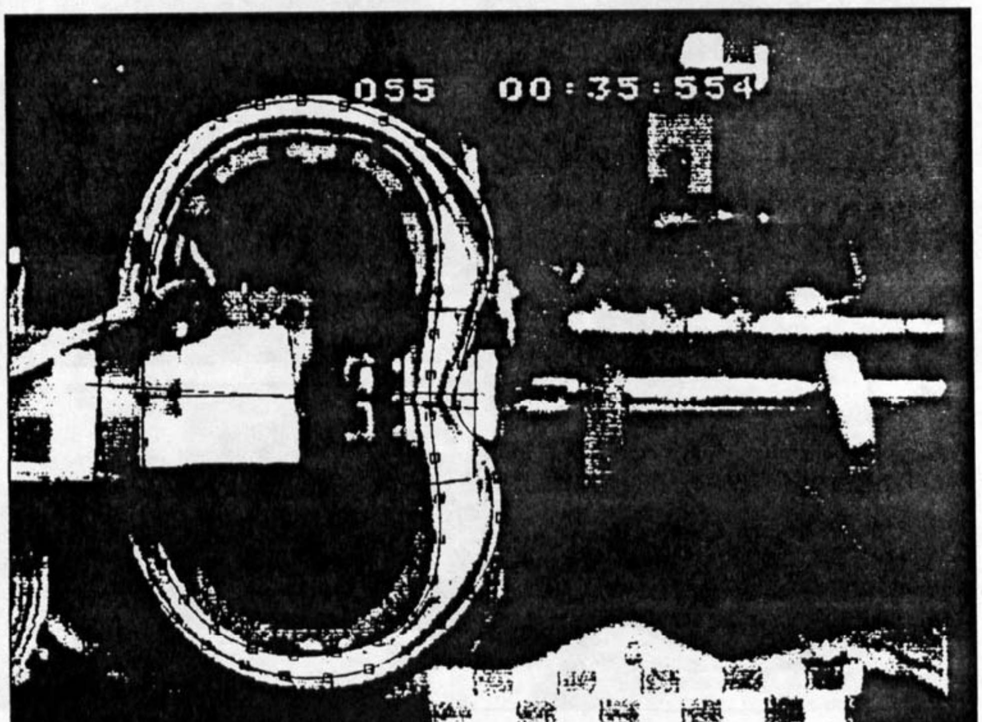

Figure 8 -- Video Image/Chest Band Plot Overlay - Test 55, t=31 msec

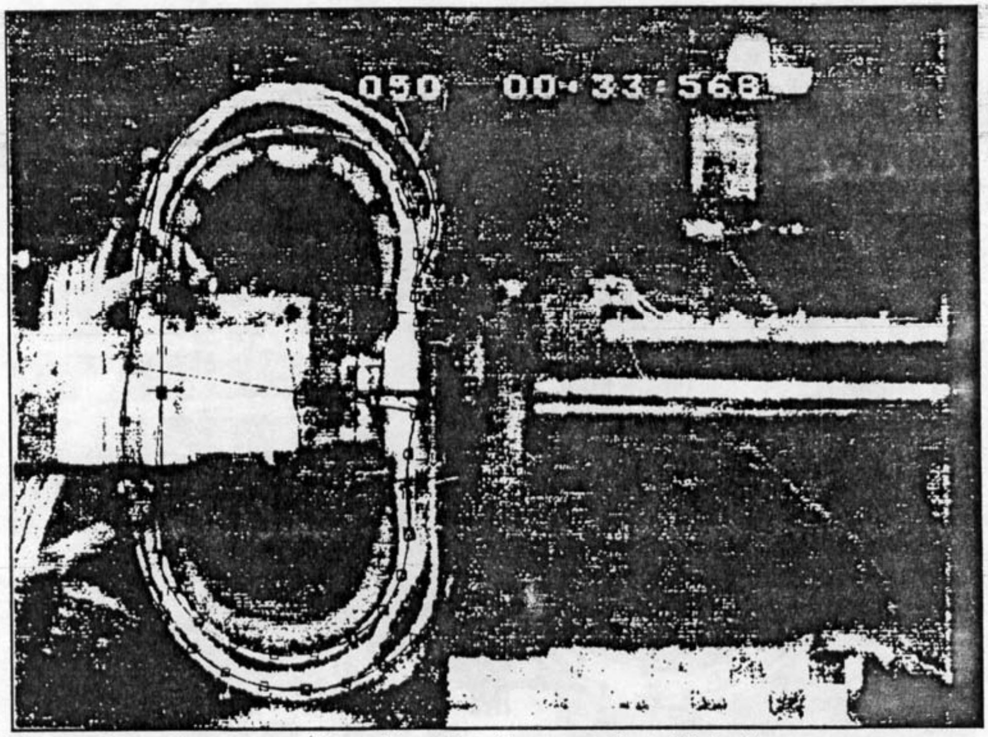

Figure 9 -- Video Image/Chest Band Plot Overlay - Test 50, t=21 sec

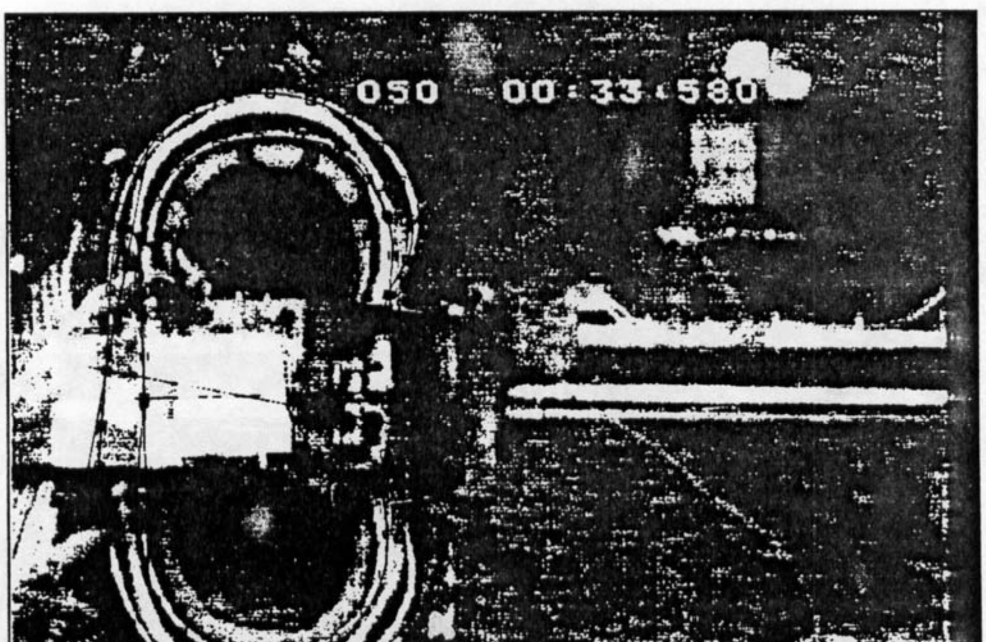

Figure 10 -- Video Image/Chest Band Plot Overlay - Test 50, t=33 sec

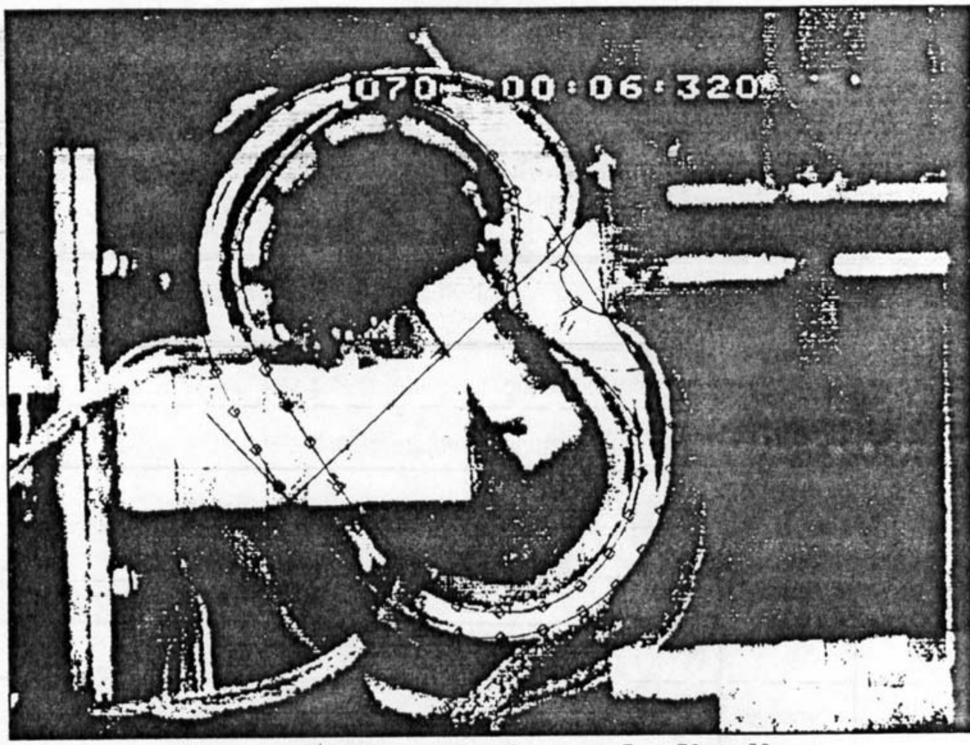

Figure 11 -- Video Image/Chest Band Plot Overlay - Test 70, t=32 sec

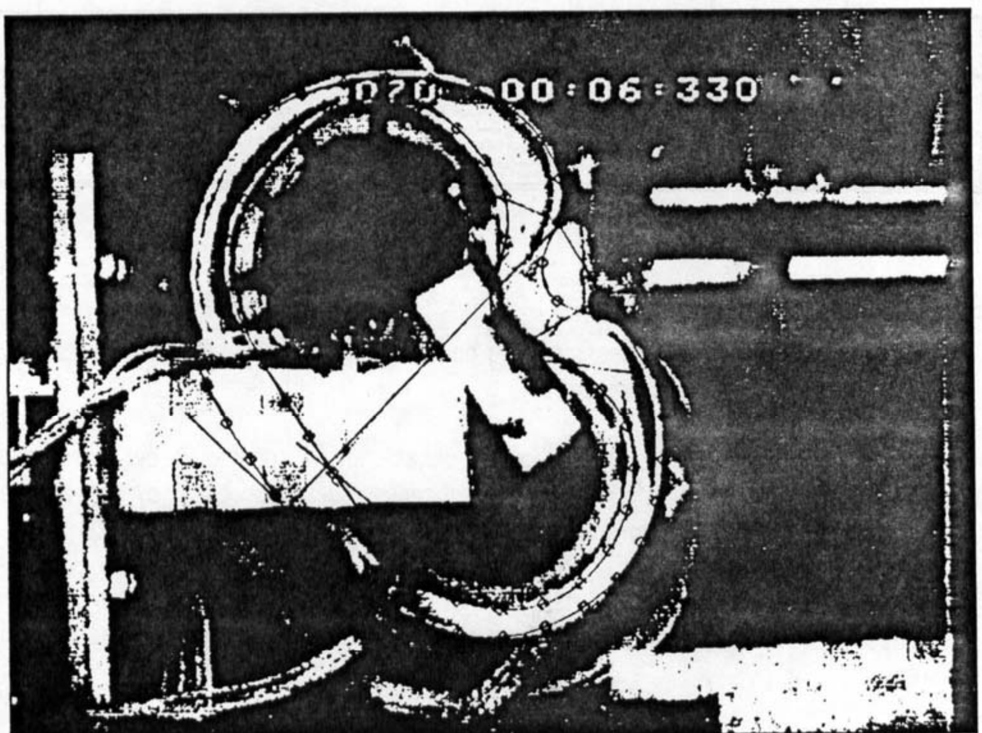

Figure 12 -- Video Image/Chest Band Plot Overlay - Test 70, t=42 sec

TABLE 3. Discrepancy explanations for chest band/video image overlays

Test	Time (msec)	Band	Reason for Discrepancy	Possible Explanation
48	21	Internal	Band not detecting curvature at mid sternum	B
	33	Internal	Band not detecting curvature at mid sternum	B
50	21	Internal	Convex curvature at sternum	C
	21	External	Too much curvature at dummy's right sternum; Not enough curvature at dummy's left sternum	A B
	33	Internal	Convex curvature at sternum	C
	33	External	Too much curvature at dummy's right sternum; Not enough curvature at dummy's left sternum	A B
59	37	Internal	Band not detecting curvature at mid sternum	B
61	21	Internal	Band not detecting curvature at mid sternum	B
70	32	Internal	Too much concave curvature at mid sternum	A
	42	Internal	Too much concave curvature at mid sternum	A

KEY TO POSSIBLE EXPLANATIONS

A. Excessive concave curvature - "sharp" edges impacting band directly over gage; large "false" concave curvatures from one or more gages which bias overall shape.

B. Curvature not detected - "sharp" curvature between gages that is undetected by gages; chest band not conforming properly to physical shape of deformation; Physical concave deflection offset by convex biasing of gages from point deflections (such as the sternum boltheads or the RTV covering the boltheads).

C. Excessive convex curvature - point curvatures such as those caused by curvature over sternum boltheads or the RTV covering the boltheads bias gage(s) and output shape; most apparent in tests with high impact velocity and large impact surface area.

contact from the flat, circular plate. This was not apparent with the cylindrical impactor, possibly due to the lesser surface contact area of impact. The video image overlay in Figure 10 also revealed that a possible "sharp" point deflection to a gage on the right side (top of figure) of the external band coupled with a "missed" curvature (between gages) on the left side (bottom of figure) created the misleading results for the external band observed in the overlay. These results indicate that the *type of contact* and *severity* of the impact environment can affect chest band output.

CONCLUSIONS

Overall, of the 10 impact tests analyzed in this project (a total of 32 time intervals were analyzed), differences between the internal band and the video images were noted in five different impact configurations and at 8 separate time intervals. For example, the internal chest band revealed discrepancies between the video image and the chest band produced plots ranging from 7.5 mm to 20 mm at the time of maximum deflection in test 50, a 5.2 m/s test using the 20.3 cm circular impactor.

The contours obtained from the external chest band in the impact tests revealed that the external band was consistent (in nearly all cases) in obtaining an accurate contour of the chest during the deflection event when compared to the video images. Exceptions included a disagreement up to 10.0 mm between the external band and the video image in a 5.2 m/s impact test using the 20.3 cm diameter circular impactor with 2.54 cm rounded edges (Test 50). This was the only discrepancy with respect to the external chest band/video image comparison in all tests analyzed.

Chest band data also revealed the influence of various impactor shapes on chest band performance. The band displayed adverse effects when subjected to impacts from the circular plate at the highest velocity analyzed. This could have been due to "edge" effects of the plate which caused excess gage curvature or "missed" curvature between gages and increased contact surface area during impact. Edge effects were most apparent in the high velocity tests. This problem was not apparent in the cylindrical impactor tests. However, the internal band did experience excessive concave curvature in some high speed cylindrical impactor tests.

Although the results from the chest bands were not always consistent with the actual deflection event, the bands performed well in most cases when compared with the video images, especially the external chest band.

Overall, the results reveal that the type of contact and severity of the impact environment can affect chest band ouput.

CONSIDERATIONS FOR CHEST BAND USE

The results of this study indicate the following considerations for using the chest band:

1. The accuracy of chest band results depends on *test environment*

- The *type* of test, whether static or dynamic can influence results. Static tests are less severe on gages than impact tests. In the tests discussed here, we found that higher velocity impacts created curvatures which sometimes lead to errors in band output. Also, the fact that these tests were conducted as localized impacts created a more ideal environment for the bands, since we could easily control the velocity and location of impact and the relationship of the gage concentration to the area of contact. Whole body tests, such as sled tests or crash tests, offer more diverse impact scenarios, which are not always predictable.

- The *geometry* of the impact face is also an important factor. An impactor with a large surface area may force the band to interact with elements such as the steel ribs or sternum plate and exaggerate gage outputs. In addition, some impact surfaces may cause "edge" effects which adversely affect the gages. Small curvatures such as those imposed by steering wheels may lead to erroneous output contours.

2. The number and spacing of active gages is *critical* to chest band performance.

- In a dynamic test environment, the more active gages on the chest band, the more confidence one can place in the ouput contour. Since it is often difficult to predict where impacts will occur along the length of the band, ideally, *all* gages should be used. Even gages opposite the struck side of the subject are important. This side may experience "bulging" or may contact some unforeseen object. Since the chest band contour depends on the curvatures around the entire circumference, error could be added to the overall contour by a lack of curvature information along any portion of the band.

- In some situations, the current 2.5 cm gage spacing may be inadequate for accurate contour reproduction. Although not currently available, a band with gages spaced more closely together may eliminate some of the inaccuracies associated with "missing" or "sharp" gage contacts. In any case, the researcher should use caution in interpreting band results, particularly in severe test environments.

DISCLAIMER

This work was conducted for the National Highway Traffic Safety Administration under contract number DNTH22-88-C-07292. The discussion and conclusions in this paper represent the opinions of the authors and not necessarily those of the NHTSA.

REFERENCES

1. Eppinger, R.H., "On the Development of a Deformation Measurement System and Its Application Toward Developing Mechanically Based Injury Indices," Paper 892426, 33rd Stapp Car Crash Conference, 1989.

2. Hagedorn, A.V., and Pritz, H.B., "Evaluation of a Chest Deflection Measurement Band," National Highway Traffic Safety Administration, DOT HS-807-838, July 1991.

DISCUSSION

PAPER: **Evaluation of Chest Band Responses in a Dynamic Test Environment**

PRESENTER: Alena V. Hagedorn, TRC

Q: John Melvin, GM.
Maybe I missed this one. What kind of methods did you use to get the optical system where you find out the contour, based on high speed photography, right?

A: Right.

Q: What kind of reproducibility or position do you have on those measurements in contrast to the chest band where you can practically go down to, I don't know, how many microns, depending on what your computer can do?

A: What kind of accuracy do I have?

Q. Um, hum.

A: It's hard to quantify accuracy, but the way that I performed this evaluation was by scaling the time slots from each test. I scaled the video image so that it is exactly overlaid with the chest band plot and then, on subsequent time intervals throughout that test, I didn't do any more scaling. I just assumed the scaling was correct, so I forced it to match on the first plot.

Q: And then whatever happened?

A: And then whatever happened, happened. And in fact, in a lot of my tests you see I only had eight out of thirty-two time intervals that showed any discrepancies. There were tests where I had perfect matches all the way through.

Q: Thanks.

A: Um, hum.

Q: David Viano, General Motor
That was a nice study. Thank you.

A. Thank you.

Q: I had one question and I didn't maybe understand, or you said something and I didn't hear it. If you run the same test that exhibits discrepancies, how repeatable are the discrepancies?

A: The results were very repeatable. In fact, we actually ran three tests of each type here and we saw the same thing. As long as you impact the same area of your test set-up the same way, we saw repeatable results.

Q: Jeff Crandall, University of Virginia
I wondered if you could comment on the attachment? How you attach the chest band to the thorax? I may have missed that.

A: OK. I didn't go over that, but I will explain. We used a Velcro technique where we put Velcro on the overlapped portion of the band. We pulled the band as tight as we could and then used the Velcro to fasten. We found that's a good way to hold the band on there without having to use tape. It's difficult on a dummy to attach it, but that's the way we've been doing it at our lab.

Q: Thank you.

Q: Frank Pintar, Medical College of Wisconsin
When you calculated your band contours, I think you used the RBAND_PC program.

A: Actually, I used a VAX version of that, which was the original.

Q: OK. That program assumes that the sternum and the spine move linearly with respect to each other. Did you play around with the analysis, moving those two points and seeing how they affect the accuracy?

A: Yes, I did. That's most important when you're overlaying the chest bands on top of each other, the plots. In fact, I found that using the tangent method on the spine of the dummy such as one inch, use a 0.1 inch on either side of the spine and then draw a line through that and that's your tangent point. That gets you a much better depiction of the chest movement through space. For these tests, it really didn't matter whether I lined it up along the spine or the sternum or along the tangent.

Q: Oh, it didn't matter.

A: Because I was getting the best fit, putting them on the figure and moving the figure in order to get the best fit overlay.

Q: I was just thinking of one, when you have the chest angled more slightly than you, then that might not hold true that the sternum moves relative to the spine.

A: That's correct. Like I was saying, usually when I analyze I use a tangent along the back of the spine. In this case, it didn't matter whether I used along the spine/sternum or not, because even if that sternum point was moving, since I was just overlaying it on the photograph and fitting it to the best fit, by eye, I didn't really use those points.

Q: What was your frame rate on the video catcher?

A: It was 500 frames per second.

Q: 500 frames.

A: Um, hum.

Q: And, in terms of time synch, how did you do that with the chest band information?

A: Right, there could be about two milliseconds of discrepancy because we're only getting the 500 frames per second, so what I did was, I took the chest band plots from time zero, time one, and time two milliseconds and overlayed them with the video image because we had a light that would come on and tell us when time zero was on the video image and, then, depending on which one of those overlayed the best on the frame with the light coming on, I considered that as my time zero and so my time zero might have been at two milliseconds.

Q: Richard Morgan, NHTSA
Alena, when I see a structure like that, I think of the chest depth. On the worst case that you showed us, what was the percent of error in the chest band measure versus the video? The distance from the front of the chest to the back, what was that percent error?

A: The percent error of deflection? The biggest difference I saw was the 20 millimeter difference between the plot and the video image and that would have occurred on my highest velocity impact, which would have given me about close to three inches of deflection.

Q: OK, but for the chest depth, what would that have been? I think of an accelerometer and ask what the accuracy is. I guess we typically say it's three percent or something like that. I was wondering what you thought that the maximum error was.

A: The maximum error is about 33% then. If it's twenty millimeters, then the maximum deflection was about...

Q: But the chest depth. What was the chest depth? The chest depth was more like 24 centimeters or something, so.

A: I don't know. I didn't look at that specifically.

Q: OK. Thank you.

A: It was 500 frames per second.

Q: 500 frames.

A: Uh huh.

Q: And in terms of time synch, how did you do that with the chest band information?

A: [illegible] there could be about two milliseconds of discrepancy because we're running the [illegible] 500 frames per second, so what I did was I took the chest band plots from time zero to [illegible] next time [illegible] milliseconds and overlayed them with the video image because we had a light that would come on and tell us when time zero was on the video image and, then, depending on [illegible] which one of those overlayed the best on the frame with the light coming on I considered that [illegible] the time zero and so my time-zero might have been at two milliseconds.

Q: Richard Morgan, NHTSA.

[illegible] Again, when I see a structure like that, I think of the chest depth. On the worst case [illegible] you tell us what was the percent of error in the chest band measure versus the video. The [illegible] distance from the front of the chest to the back, what was that percent error?

A: [illegible] percent error of deflection? The biggest difference I saw was the 20 millimeter [illegible] difference between the plot and the video image and that would have occurred on an [illegible] deflection impact, which would have given me about close to three inches of deflection.

Q: OK. In the chest depth, what would that have been? I think of an accelerometer and ask [illegible] about its accuracy and I guess we typically say it's three percent or something like that. I was wondering what you thought that the maximum error was.

A: The maximum error is about 33% then. If it's twenty millimeters, then the maximum [illegible] deflection was about [illegible]

Q: But the chest depth. What was the chest depth? The chest depth was more like 24 [illegible] centimeters or something, so

A: I don't know. I didn't look at that specifically.

Q: Okay. Thank you.