MECHANICAL COUPLER TESTING REPORT

for

Barsplice Products

Interim Report for Models:
■ 8XL-2Y Bargrip XL Swagged (orange)
■ 8XL-2Y Bargrip XL Part Swagged (red)
■ 8B-2Y Bargrip Swagged (yellow)

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July 1994

Executive Summary

Three styles of Barsplice couplers were tested at the University of Kansas Structural Engineering and Materials Laboratory. The couplers tested and reported include six 8XL-2Y Bargrip XL Swagged (orange), six 8XL-2Y Bargrip XL Part Swagged (red) and eight 8B-2Y Bargrip Swagged (yellow) systems. This report includes the test setup, procedures, results, and evaluation of these testing activities.

The summary of results indicates that the three types of No. 8 bar coupler models performed quite well under monotonic, step cyclic, and uniform cyclic loading. No systematic failures were encountered in any coupled assembly under the strength and strain criteria that were set forth in the testing program. The results indicate that these systems can achieve the levels of ductility typically required of reinforced concrete connections under severe lateral loading.

Certification:

I hereby certify that the results and evaluation contained in this report were performed by me or under my direct supervision. I further attest to their accuracy and to the conclusions contained in this report.

Steven L. McCabe, Ph.D., P.E.

Table of Contents

	Page
Chapter 1 Introduction	1
Chapter 2 Testing Configuration	3
Chapter 3 Testing Results and Evaluation	11
Chapter 4 Conclusions	23
Appendix	25
Tables	27
Figures	28
Model 8XL-2Y Bargrip XL Swagged (Orange)	29
Model 8XL-2Y Bargrip XL Part Swagged (Red)	30
Model 8B-2Y Bargrip Swagged (Yellow)	31

Chapter 1

Introduction

The purpose of this testing program was to ascertain how well typical commercial quality mechanical coupler systems as produced in the United States would perform under simulated seismic loading. This program was in response to an inquiry by ACI 318-H, the Seismic Subcommittee of the main Building Code Committee. Current ACI 318 provisions require "only" that the coupled system meet 125 percent of the nominal yield of the bar. This requirement is intended to satisfy the situation where overstrength bars are coupled by the mechanical system; a system typically found in practice. Thus, current code provisions address strength only.

The question of how the same coupler systems would perform under severe lateral loading, such as lateral loading produced by an earthquake, in which perhaps significant inelastic demands are made on members and connections is an entirely different consideration. In these cases, the ability to maintain load capacity well into the inelastic regime is the issue and may not be satisfied by a strength-only criteria. As such, Subcommittee 318-H inquired of ACI 439 as to what the committees opinion was as to the viability of the 125 f_y criterion, as presently stated in the Code. This research effort was a direct result of that inquiry and is intended to answer the question posed by 318-H with as satisfactory a technical answer as is possible.

Accordingly, participation was solicited by the industry and the No. 8 bar coupled assemblies were supplied to the University of Kansas Structural Engineering and Materials Laboratory. Assemblies for testing were obtained from each manufacturer participant. These assemblies were divided into three groups. One group was pulled monotonically to failure, a second group was cycled to 4 percent strain uniformly over 16 cycles and then pulled to failure. These two testing regimes represented the original concept for this program. The third group of specimens was step cycled. That is, the assemblies were cycled 4 times to 2 percent strain and the strain was increased in half percent increments, with each increment applied over 4 cycles. Following 16 complete cycles, the coupler assembly was pulled to failure.

In this report, the testing setup, test specimen configuration, instrumentation and testing procedure are presented. Test results and evaluation of the results are also provided.

As will be shown, the results indicate that the Barsplice specimens met the criteria set by the planners of this testing program. The overall ductility levels that were reached met or exceeded the nominal 4 percent values thought to be needed for ductile systems for use in seismically resistant design. What follows, therefore, is the description of this testing program and the evaluation of these results.

Chapter 2

Test Methodology

2.1 Materials

The reinforcing steel used for all tests was supplied by Birmingham Steel. These samples were No 8 bars made of Grade 60, A615 steel from a single source and heat. The reinforcing steel was selected to be as strong as possible but with an actual yield strength not to exceed 78 ksi and was intended to perform like A706 steel. This ensured that the strength and ductility demands on the mechanical connections would be as great as possible. That is, the engineering stress-strain curve for the reinforcing bars should exhibit as high a stress as possible at 4 percent strain in tension, which was determined to be the maximum required strain for the connection. Although the use of such high strength steel is conservative, it was considered necessary to ensure that maximum demand was placed on the mechanical couplers [Ref 4]. See Fig. 1 for a typical stress-strain curve for the reinforcing steel.

All mechanical connections were supplied to the University of Kansas Structural Engineering and Materials Laboratory. With some styles of couplers it was necessary that the connection of the two bars be completed at the coupler suppliers' location. Other styles were shipped unassembled to the University of Kansas and then assembled on site in strict accordance with directions supplied by the manufacturer. All fabrication of the actual coupler components was performed at the manufacturers location and it was their responsibility to ensure that a proper connection between the two bars was achieved.

2.2 Test Set Up

Test Machine All testing was performed on a servohydraulic test system manufactured by the Instron Corporation. The system, Model 1334, had a load rating of ± 100 kips with a stroke range of ± 5.0 inches. For all testing, the system was used in the 100% load range and 50% (± 2.5 inches) stroke range. Load was read from the machine load cell; a copy of the machine calibration is found in Appendix A.

Strain Measurements The primary strain measurement to be considered was the 20 bar diameter gage length which encompasses both the mechanical coupler and the two bars. The decision to use 20 bar diameters as a gage length was based on the recommendation of ACI Committee 368. In a typical beam with No. 8 longitudinal reinforcing bars, the 20-inch gage length was intended to represent the distance over which the effect of any stiffness or softness (compared to the reinforcing bar) of the mechanical connection could be considered to be distributed relative to structural response [Ref 5]. ACI Committee 439 also stated that the 20-inch gage length was a target value and could be adjusted if considered practical. For the actual testing, the gage length used was approximately 20 to 21-inches due to physical limitations of the testing apparatus. However, for the purpose of this report the nominal gage length will be used and will be referred to as "20 bar diameters" or the "20-inch gage length". Actual gage lengths were measured and used for evaluation of results.

The strain specified to be measured for determination of the mechanical couplers adequacy for seismic use was the <u>average</u> strain measured across the entire 20 bar diameter gage length. This gage length straddled the mechanical connection with the coupler itself being centered within the 20 inch length. The strain was determined indirectly by measuring the elongation, Δ, of the mechanical connection which was then divided by the exact overall gage length, L.

The elongation was measured using Linear Differential Variable Transformers (LVDT's). Three LVDT's were placed at 120 degree intervals around the circumference of the mechanical connection. The LVDT's used were Lucas Schaevitz HR-DC 2000's which have a +/- 2.0 inch linear range. The device used for holding the LVDT's was designed and built "in-house" and was held in place over the gage length by three set screws positioned at 120 degree intervals at the top and bottom of the LVDT assembly (see Fig. 2). The purpose of using three measurements taken at 120 degree intervals was to account for any initial lack of straightness of the connector/bar assembly and to insure accurate elongation measurements throughout the testing, both for monotonic and cyclic loading tests. The elongation of the assembly was taken from the LVDT's in terms of voltage and were then converted to a linear measurement by multiplying the measured voltage by a scale factor for each corresponding LVDT. The three elongations were then averaged to determine the average overall elongation. This average elongation was divided by the original gage length of the coupler/bar specimen to determine the average strain value to be used in the evaluation of the mechanical coupler.

A second strain measurement was taken on the exterior of the mechanical coupler itself. A micro extensometer (MTS Corporation: Model 632.11B-20) was used to take this measurement. The extensometer has a pre-set one inch gage length. A voltage was taken off the extensometer and converted to an elongation by the use of a scale factor in the same way as that of the LVDT voltage (see Appendix A). This strain reading could then be plotted against the corresponding load and compared to the LVDT strain across the 20 bar diameter gage length of the mechanical connection. The extensometer was held in place with heavy rubber bands. The knife edges of the extensometer were seated in place by slightly scoring the exterior of the connector in an attempt to insure that no slippage would occur during the testing. This had no effect on performance. Slipping/jumping of the extensometer could not always be prevented due to the reaction of the connection to the extreme loading to which it was subjected. The coupler extensometer was removed during each test prior to the failure of the mechanical connection in order to prevent damage to the extensometer from the release of energy that resulted from the material failure of either the coupler itself, or the steel reinforcing bar when the mechanical connection failed.

A third strain measurement was taken off of the steel reinforcing bar itself at a point centered between the coupler and bottom jaw grip. This distance was normally in the range of 7 to 8 inches from the center-line of the specimen. This measurement was always taken in the bottom one-half of the bar/coupler assembly in order to allow for the physical ease of connecting the extensometer. The measuring device was of the same type as that used to measure the strain at the center of the mechanical coupler. The set-up and attachment to the specimen were identical for the two extensometers. The reinforcing steel was again slightly scored in the same way as the mechanical coupler to allow the seating of the knife edges of the extensometer.

2.3 Test Methodology

General To determine the strain capacities of the mechanical coupler assemblies a standard test procedure was developed. It was determined by ACI Committee 439 that the mechanical coupler assemblies should undergo three different types of tests: 1) a monotonic tensile test to failure, 2) a stepped strain cyclic load test and, 3) a uniform cyclic load test. For all tests, the strain average was measured over a 20 bar diameter gage length that included the connector and portions of the two reinforcing bars being coupled. The stepped and uniform strain cyclic tests were conducted over 16 cycles and then pulled monotonically to failure. A maximum of nine tests was run on each coupler system that passed all the test criteria.

Test Description Three separate types of tests were conducted to evaluate the load vs. strain behavior for the mechanical couplers. The purpose was to determine the coupler performance, and also to ascertain which of the tests would subject the couplers to the most severe loading condition while still remaining a feasible testing procedure.

Monotonic Loading The first test performed on all coupler assemblies was a monotonic tension loading of the coupler/bar assembly. The specimen was loaded from zero strain up through the 4 percent strain requirement and then on out to failure

(0 in/in → failure). Each test was performed similar to the tension test specified in ASTM 370A for determining the yield strength of steel. Load/Strain rates were kept within ASTM 370's specification parameters using a load rate between 0.1 kips/minute as a minimum and 100 kips/minute as a maximum. The target load rate was maintained at approximately 60 kips/minute (76 ksi/minute).

Stepped Cyclic Loading Once the coupler assembly passed the monotonic load test, it was next subjected to the Stepped Cyclic Load test. For this test the specimen began at initial conditions of zero strain under zero load. Next the coupler assembly was loaded in the same manner as in the monotonic load test but only until the average strain across the 20 bar diameter reached 2 percent. At this point in the test the load was "turned around" and the specimen was unloaded through a load of zero kips into a target compression load of 10 kips (12.7 ksi). The purpose of compressing the coupler assembly was to insure that the coupler itself underwent complete unloading in tension before being subjected to the next cycle of tension loading. The target compressive load of only 10 kips was to ensure that a failure due to buckling did not occur while subjecting the coupler to a significant compressive load so as to "click" the coupler from tension into compression. After being compressed the assembly was then cycled four times under a tension load out to 2 percent strain. After this tension-to-compression cycle to 2 percent strain was completed four times, the testing was repeated at strain values of 2.5, 3.0 and 3.5 percent strain. At each strain level, the testing cycle was conducted four times. After the final unloading at the 3.5 percent strain the assembly the loaded in tension out to failure. The loading sequence is described as follows:

Stepped-Cyclic Loading Procedure

2.0% strain → 10 kips (12.7 ksi) compression (4 cycles)

2.5% strain → 10 kips (12.7 ksi) compression (4 cycles)

3.0% strain → 10 kips (12.7 ksi) compression (4 cycles)

3.5% strain → 10 kips (12.7 ksi) compression (4 cycles)

0 KSI → failure (1 cycle)

Uniform Cyclic Loading The third and final type of test that the coupler specimen were subjected to was the Uniform Cyclic Load test. In this test, the coupler assembly was loaded from zero strain at zero load out to a full 4 percent strain on the first load cycle. Upon reaching the 4 percent strain value the assembly was unloaded back through zero load to a target compression load of 10 kips (12.7 ksi). This cycle was completed a total of sixteen times. After the sixteenth cycle the specimen was then loaded until failure. The loading cycle can be described as follows:

Full Cyclic Loading Procedure

0 in/in → 4.0% strain → 10 kips (12.7 ksi) compression

(16 cycles)

0 KSI → failure (1 cycles)

A total of six to nine tests were conducted, depending on the number of specimens supplied, under the testing methodology described. Results of the testing are contained in the following chapter.

Chapter 3

Testing Results and Evaluation

The specimens from the three Barsplice models that were tested at KU in accordance with the procedures previously described. Six Model 8XL-2Y Bargrip XL Swagged specimens were color coded "orange", six 8XL-2Y Bargrip XL Part Swagged specimens were color coded "red", and eight 8B-2Y Bargrip Swagged specimens were coded "yellow." The specimens were divided into monotonic, stepped cyclic and uniform cyclic test groups. Monotonic tests were performed first, followed by the cyclic tests. Specimens that failed the monotonic test criterion of 4 percent could not be expected to meet a cyclic test to 4 percent, so the monotonic tests were performed first to evaluate the overall ductility of the assembly. The results will be presented for each model of the coupler.

Model 8XL-2Y Bargrip XL Swagged (Orange)

Monotonic Test Results

The first series of tests was the monotonic series in which specimens were taken under monotonic loading to failure. In Figs. 3 and 4, the results of this monotonic testing can be seen. The "a" figures in this series represent the data plotted as stress, that is, the load versus strain data divided by 0.79 square inches, the area of the No. 8 bar. The "b" figures are load versus strain plots for these monotonic tests.

Load is in kips, strain is in inches per inch and represents that average value obtained from the LVDT data from these tests.

As can be seen from these figures, both monotonic tests met and exceeded the 4 percent nominal criteria that was set by the ACI 439. The first test failed at 5.2 percent strain, the second test at 9.3 percent strain. During this second test, the LVDT assembly slipped when the specimen was taken from 2.1 to about 2.8 percent strain. The assembly was retightened and failure occurred at an uncorrected value of 9.3 percent, a value that may be high by 0.5 percent. It is significant to note that the failure of the first monotonic test occurred at a flaw in the rebar, well away from the coupler.

The failure noted in the second monotonic test also was observed to occur in the bar. Extensometer data for the rebar closely follow the LVDT data, while the coupler is observed to be quite stiff. It can be seen that the coupler strain is significantly lower than that of the system or the bar.

The failure of the coupler assembly at 5-9 percent strain can be compared to the steel bar itself where failure was observed at 10-13 percent strain. Thus, there is a reduction in ductility when the coupler is present, however, significant strain levels can still be achieved. All the assemblies exceeded the current ACI requirement that the coupler be able to develop 125% of the nominal yield of the bar.

Stepped Cycle Tests

The next two specimens were subjected to the stepped cyclic testing regime in which the bar was pulled monotonically to 2 percent strain and then unloaded to approximately 10 kips of compressive load (12.7 ksi) over two cycles. This load-unload pattern was accomplished four times, followed by loading the bar monotonically to 2.5 percent strain, unloading the bar and reloading it to the same strain four times. This was followed by pulling the bar to 3 percent strain, unloading it, and loading it slightly into compression. This was repeated four times, with the final set of four cycles commencing at 3.5 percent strain and then the bar being pulled to failure. Results are presented in Figs. 5 and 6.

The results of these figures include the LVDT average data, which is plotted as a dotted line, the coupler extensometer data which is a longer dashed line, and outer extensometer which is a solid line. As can be seen from these results, the LVDT average data and the bar extensometer indicate yield at the same point. However, it can be seen that once yielding occurs, the strain in the bar is approximately a full percent greater than in the overall system. Failure levels were observed at approximately 5 percent strain and 7.4 percent strain. Again the 'a' figures are in terms of stress and the 'b' figures are in terms of load. In the first stepped cycle test, Fig. 5, the specimen was on the 16th cycle and was at a strain of 3.5 percent when a hydraulic system failure occurred. The problem was repaired and the specimen reloaded, but without the LVDT and other instrumentation. The specimen was observed to fail at 87 kips (110 ksi) and an estimated strain of 6.5 percent.

In Fig. 6, there is a clear failure point at 7.4 percent that occurs after the cyclic loading when the coupler was monotonically pulled. Failure occurred in the bar itself, in between the coupler and machine jaw. There is no outer extensometer data at this point because they were removed prior to loading the specimen to failure. The coupler is very stiff which forces most of the strain into the bar itself. It can be noted in this figure, as well as others, that there is very little hystersis that occurs as the specimen is put into compression and the bars reseat themselves during the loading process. This lack of hystersis indicates a good connection between the bar and coupler.

Uniform Cyclic Testing

As can be seen in Figs. 7 and 8, the data is reported for the two assemblies that were tested out to 4 percent strain, unloaded and then loaded to approximately 10 kips (12.7 ksi) compression and then reloaded back to the original 4 percent value, this process repeated 16 times. LVDT data for the 20 bar diameter gage length is reported, as is extensometer data for the steel or outer extensometer, and the mechanical coupler extensometer.

In these tests, specimens failed at 7.3 and 7.8 percent strain. In both figures, the clear yield corner can be seen and the cycles are virtually on top of one another. the specimen completed all 16 cycles and failed when the monotonic pull to failure was initiated following the cyclic testing. It can be seen that the mechanical coupler is experiencing maximum strains of approximately 0.25 percent, while the bar itself is experiencing strains of 5 percent; the coupler assembly is at 4.0 percent. Yields are clearly seen in this system. The specimens once again failed when the cycling process was completed and the specimens were being pulled monotonically to establish the failure loads.

The summary of the overall testing can be seen in Table 1. It can be seen that all the test specimens maintained the 125 f_y criterion regardless of the testing regime. Moreover, all specimens exceeded the 4 percent strain criterion and did not exhibit any reduction in failure stain when cycled.

Model 8XL-2Y Bargrip XL Part Swagged (Red)

Monotonic Test Results

In Figs. 9 and 10, the results of the monotonic testing are presented as before, the "a" figures in this series represent the data plotted as stress, that is, the load versus strain data divided by 0.79 square inches, the nominal area of the No. 8 bar. The "b" figures are load versus strain plots for these monotonic tests. Load is in kips, strain is in inches per inch and represents the average value obtained from the LVDT data from these tests.

Both monotonic tests exceeded the 4 percent nominal criteria set by ACI 439. The first specimen failed at 7.1 percent strain and the second at 8.1 percent strain.

The failures noted in the first monotonic test were observed to occur at the coupler midpoint, Fig. 9, with the second test failing in the bar. Extensometer and LVDT data all are grouped closely together for both tests. The coupler bar and assembly strains are very similar until about 4 percent is reached in the assembly. The extensometer was removed at this point as the specimen was pulled to failure.

The failure of the coupler assemblies at 7-8 percent strain can be compared to the steel bar itself where failure was observed at 10-13 percent strain. As before, there is a reduction in ductility when the coupler is present. In this system, there is about a 25 percent reduction in ductility. Also, all the assemblies exceeded the current ACI requirement that the coupler be able to develop 125% of the nominal yield of the bar.

Stepped Cycle Tests

The next two specimens were subjected to the stepped cycle testing regime. Results are presented in Figs. 11 and 12.

The results of these figures include the LVDT average data, which again is plotted as a dotted line, the coupler extensometer data which is a longer dashed line and the outer extensometer which is a solid line. As can be seen from these results, the LVDT average data lags both the coupler and bar strain data. The strain in the bar is approximately half a percent lower than that in the overall system. The strain in the coupler is quite large, roughly twice that in the assembly. This means that on the last series of cycles, the coupler is "feeling" 8 percent strain. Failure levels of strain were observed at 8.7 percent and 8.5 percent strain in the assembly.

In both tests, failure occurred in the coupler itself, and the load quickly dropped off. No extensometer data is available at these large strains because the extensometers were removed prior to loading the specimen to failure. It can be noted in these figures that there is a small amount of hystersis that occurs as the specimen is put into compression and the bars reseat during the compression process.

Uniform Cyclic Testing

As can be seen in Figs. 13 and 14, the data is reported for both assemblies that were tested using the 16 cycles of 4 percent strain. LVDT data for the 20 bar diameter gage length is reported for both tests, although slippage of the LVDT assembly occurred in the first test, Fig. 13. Extensometer data is plotted for the steel or outer extensometer, and the mechanical coupler extensometer in both tests. Slippage of the rebar extensometer occurred in this second test.

In these tests, specimens failed at 6.6 and 8.2 percent strain. In Fig. 13, the specimen completed all 16 cycles and failed when the monotonic pull to failure was initiated following the cyclic testing. Assembly and rebar strain are similar; again the coupler strain was large, in this case over 1 percent. Results for the second specimen are found in Fig. 14; data for the LVDT average and the extensometers on the rebar and the coupler reveal large coupler strain. It can be seen that the mechanical coupler is experiencing maximum strains of approximately 8.2 percent in this test, as measured on the coupler. The specimens once again failed in the coupler when the cycling process was completed and the specimen was being pulled monotonically to establish the failure loads.

The summary of the overall testing for this model can be seen in Table 2. All the test specimens exceed the 125 f_y criterion, regardless of the testing regime. In addition, all specimens exceeded the 4 percent strain criterion set by ACI 439.

8B-2Y Bargrip Swagged (Yellow)

Monotonic Test Results

The first series of tests were the monotonic series in which three specimens were taken under monotonic loading to failure. In Figs. 15 to 17, the results of this monotonic testing can be seen. Again, the "a" figures in this series represent the data plotted as stress with the load versus strain data plots for these monotonic tests. Load is in kips, strain is in inches per inch and represents the average value obtained from the LVDT data from these tests.

As can be seen in these figures, once again all three monotonic tests met and exceeded the 4 percent nominal criteria that was set by ACI 439. The first test failed at 9.3 percent strain, the second test at 7.8 percent strain and the third test exhibited failure at 6.0 strain.

The failures noted in this monotonic testing were observed to occur at the midpoint between the coupler and LVDT fixture, Figs. 15 and 16, and the bar pulled free of the coupler in the third test. No extensometer data was available for the bar or coupler in Fig. 15 or for the bar in Fig. 16. Full bar, coupler and LVDT data is available for the third test, Fig. 17.

The data from the first test, revealed the LVDT data exhibiting excellent ductility out to 9.33 percent strain, measured over the $20d_b$. In test 2, the bar-coupler assembly once again was quite ductile with failure occurring at 7.84 percent. A slight slippage of the LVDT fixture occurred at about 6 percent and can be seen in the data. This slippage occurred because of area reduction in the bar. Therefore, the "true" failure strain is probably 0.5 percent, or more, in excess of 7.84 percent. The extensometer data for the coupler itself reveals very stiff behavior with little inelastic behavior occurring.

The final monotonic test, Fig. 17, had all three data points plotted. Once again the system was ductile and the coupler quite stiff. The bar exhibited two slippage points, one at 6 percent which began a slow drop in load capacity with increasing strain; final pullout of the bar occurred at nearly 12 percent strain. There was a slight amount of slippage in the LVDT fixture that occurred at about 4 percent strain. This was corrected during the test, but can be seen in the plot. Rebar strain was plotted and closely followed that of the assembly. However, the strains in the bar were less than that in the assembly. Since the coupler strain was very low, it is concluded that the bar was slipping slowly out of the coupler, resulting in the large strains in the assembly. Bar strains were large in spite of the slippage revealing strains of 4 percent at pullout.

As with the other systems, there is a reduction, but not a significant one, in ductility when the coupler is present. Moreover, all the 8B-2Y assemblies exceeded the current ACI requirement that the coupler be able to develop 125% of the nominal yield of the bar under monotonic loading.

Stepped Cycle Tests

The next three specimens were subjected to the stepped cyclic testing regime including 16 cycles of loading broken down into 4 groups of 4 cycles starting at 2 percent strain and then being incremented by 0.5 percent increments. The bar was pulled monotonically to failure after the final cycle. Results are presented in Figs. 18 to 20.

The results in Fig. 18 include the LVDT average data, plotted as a dotted line, and the coupler extensometer data which is a longer dashed line. There is a failure point at 9.4 percent that occurs after the cyclic loading when the coupler was monotonically pulled. Failure occurred in the bar itself when the load began to gradually drop off. There is no outer extensometer data for this particular specimen because of instrumentation problems. It can be noted in this figure, as well as others, that some hystersis occurs as the specimen is put into compression and the bars reseat during the compression loading process. The other interesting thing is the fact that the cycles measured on the coupler reveal elastic behavior, slippage of the extensometer did occur causing the curves to be translated on the plot.

In Fig. 19, once again, the LVDT data across the steel coupler assembly is greater than the strain seen in the coupler extensometer. The specimen was observed to fail at a strain of 8.9 percent with the hystersis in this specimen being less than the first stepped test.

In Fig. 20, it can be seen that once again the mechanical coupler extensometer experiences a low level of strain and the overall assembly failed at 7.7 percent. The assembly strains were greater than that of the coupler, and it can be seen in this, and all the figures, that there is a reseating of the bar and resulting hysteresis that occurs as the specimen is placed into compression. This behavior was consistently observed in all of the tests as the systems were unloaded, and reloaded in compression.

Uniform Cyclic Testing

The last two specimens, Figs. 21 and 22, were pulled to 4 percent strain, unloaded and then loaded to approximately 10 kips (12.7 ksi) compression and then reloaded back to the original 4 percent value, this process repeated 16 times. LVDT data for the 20 bar diameter gage length is reported for both tests. Extensometer data is plotted for the mechanical coupler extensometer for the second test only.

In these tests, specimens consistently failed at 8.8 and 8.9 percent strain. In Fig. 21, there can be seen a clear yield corner and the assembly cycles are virtually on top of one another. The specimen completed all 16 cycles and failed when the monotonic pull to failure was initiated following the cyclic testing. Results for the second specimen are found in Fig. 22. Data for the LVDT average and the coupler extensometers are noted. Moreover, it can be seen that the mechanical coupler is experiencing maximum strains of approximately 0.4 percent. The specimen once again failed when the cycling process was completed and the specimen was being pulled monotonically.

The summary of the overall testing for this third system can be seen in Table 3. All of the test specimens maintained the 125 f_y criterion regardless of the testing regime, and far exceeded the nominal 4 percent failure criterion set for this testing.

In summary, the Barsplice coupler models met the demands in the three types of test regimes. The three test series reveal that the three coupler models can exceed the 4 percent average strain criterion, while maintaining load capacities, as observed during the testing program. These couplers are capable of generating large levels of ductility. The "orange" system forces strains primarily into the bar, while the "red" model focussed the strain in the coupler itself. The "yellow" system also strained the bar, with some slippage occurring in the coupler-bar connection.

Chapter 4

Conclusions

From the foregoing tests, it can be seen that the monotonic testing established quite ductile behavior for these assemblies and strains that were either at or greater than the 4 percent criterion. As with results seen in other mechanical coupler systems, the presence of the cyclic testing does not seem to alter the basic performance characteristics of the system and does not indicate that there are any significant advantages to be gained in performing a stepped cyclic testing regime. The monotonic and uniform cyclic testing establishes that these Barsplice systems exceed the 4 percent criteria, as well as establishes that these systems can maintain load capacity over the 16 cycles.

The "orange" system, Model 8XL-2Y Bargrip XL Swagged focussed strain in the bar itself and exhibited a very stiff, elastic coupler. The "red" Model 8XL-2Y Bargrip Part Swagged performed differently in that the coupler itself absorbed the strain, finally failing under load. Thus, both systems meet the "acceptance" criteria, but through different mechanisms. The final model "yellow", the 8B-2Y Bargrip Swagged system, revealed once again a stiff, essentially elastic coupler and moderate bar strains. This system appeared to exhibit some degree of bar slippage relative to the coupler, resulting in large bar-coupler assembly strains.

The conclusion is that all three systems are capable of generating the load capacities and strain that can be expected under severe seismic loadings.

References

1. ASTM A 370 - 91a, "Test Methods and Definitions for Mechanical Testing of Steel Products," 1992 *Annual Book of ASTM Standards*, Vol. 1.04, American Society for Testing and Materials, Philadelphia, PA, pp. 203-248.

2. ASTM A 615 - 90, "Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement," 1992 *Annual Book of ASTM Standards*, Vol. 1.04, American Society for Testing and Materials, Philadelphia, PA, pp. 389-392.

3. ASTM A 706/A 706M-90, "Standard Specification for Low-Alloy Steel Deformed Bars for Concrete Reinforcement, 1992 *Annual Book of ASTM Standards*, Vol. 1.04, American Society for Testing and Materials, Philadelphia, PA, pp. 488-491.

4. Committee correspondence between John F McDermott and committee members dated November 25, 1991.

5. Letter from John F. McDermott, Chairman-ACI 439, to Members of ACI Committee 439 dated July 16, 1991.

Appendix

Calibrations

Appendix - Calibration

Extensometer Calibration Certification Sheet

Extensometer Serial No.	Calibration Coefficient (Volts/5mil)
#281	0.000476
#495	0.000462
#527	0.000472

Date Calibrated: July 6, 1992

Calibrated by: David L. Schlimme

Steven L. McCabe

Certified: Steven L. McCabe, Ph.D., P.E.

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        SCHAEVITZ engineering

                         02/06/92

MODEL 2000 HR-DC     S/N 1286
SCHAEVITZ PART NO.02560557-000


            DC       CALC
 INCHES    VOLTS     VOLTS    DEVS.

 -1.9997   -7.146    -7.110   -0.035
 -1.6002   -5.694    -5.689   -0.005
 -1.2009   -4.248    -4.269   +0.021
 -0.8011   -2.795    -2.847   +0.052
 -0.4007   -1.393    -1.423   +0.030
 +0.3988   +1.390    +1.421   -0.031
 +0.7988   +2.795    +2.844   -0.049
 +1.1993   +4.245    +4.269   -0.024
 +1.5992   +5.696    +5.691   +0.004
 +1.9991   +7.151    +7.114   +0.037

LINEARITY =  0.36%

SCALE FACTOR =    3.557 V/IN
```

The following cautions should be observed at all times:

Do not machine, grind, or tap any part of an LVDT core.

Do not interchange cores: cores and coils are precisely matched on assembly.

When clamping the LVDT, do not exert more force than is necessary to hold it firmly. Physical stress may affect its operation.

Lucas Schaevitz, Inc.
7905 N. Route 130
Pennsauken, NJ 08110-1489
Tel: (609) 662-8000
FAX: (609) 662-6281

```
          SCHAEVITZ Engineering
                              02/07/91

MODEL  2000 HR-DC      S/N 1252
SCHAEVITZ PART NO 2560557-000

                 DC         CALC
INCHES          VOLTS       VOLTS     DEVS
                                      -0.030
-1.9994        -7.040      -7.010     -0.007
-1.6001        -5.615      -5.608     +0.044
-1.1994        -4.158      -4.202     +0.034
-0.7998        -2.765      -2.799     +0.020
-0.4000        -1.376      -1.396     -0.031
+0.4004        +1.383      +1.413     -0.036
+0.8000        +2.780      +2.816     -0.017
+1.1998        +4.202      +4.219     +0.004
+1.5999        +5.627      +5.624     +0.028
+2.0000        +7.056      +7.028

LINEARITY =  0.31%

SCALE FACTOR =     3.510 V/IN
```

wing cautions should be observed at all times:

Do not machine, grind, or tap any part of an LVDT core.

Do not interchange cores: cores and coils are precisely matched on assembly.

When clamping the LVDT, do not exert more force than is necessary to hold it firmly. Physical stress may affect its operation.

Lucas Schaevitz Inc.
7905 N. Route 130
Pennsauken, NJ 08110-1489
Tel: (609) 662-8000
FAX: (609) 662-6281

```
            SCHAEVITZ Engineering

                                      02/08/91

MODEL 7000 HR-DC       S/N 1270
SCHAEVITZ PART NO 2566557-000

                 DC        CALC
 INCHES        VOLTS       VOLTS       DEVS

 -1 9994     -7 382     -7 383     +0 002
 -1 6000     -5 888     -5 907     +0 019
 -1 2003     -4 437     -4 430     -0 007
 -0 8004     -2 952     -2 951     -0 001
 -0 3997     -1 478     -1 470     -0 008
 +0 3996     +1 474     +1 484     -0 011
 +0 7995     +2 961     +2 963     -0 002
 +1 1996     +4 428     +4 442     -0 014
 +1 5995     +5 917     +5 920     -0 003
 +1 9994     +7 423     +7 398     +0 025

LINEARITY =  0 17%

SCALE FACTOR =    3 696 V/IN
```

iesa

/inch

inch

The following cautions should be observed at all times.

- Do not machine, grind, or tap any part of an LVDT core.
- Do not interchange cores: cores and coils are precisely matched on assembly.
- When clamping the LVDT, do not exert more force than is necessary to hold it firmly. Physical stress may affect its operation.

Lucas Schaevitz Inc.
7905 N. Route 130
Pennsauken, NJ 08110-1489
Tel: (609) 662-8000
FAX: (609) 662-6281

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INSTRON
Instruments and Systems for
Advanced Materials Testing

Certificate of Verification

This is to certify that the following described testing machine has been calibrated by us and the loading range(s) have been found to be within a tolerance of ±.5% ☒ ±1.0% ☐

Machine Model 1334
S/N 0003
Location University of Kansas
Date of Verification 6/17/92

Load Cell Type 3156-115
Capacity 100,000 lbs Ten. & Comp.
Serial No. 1089

CALIBRATION APPARATUS - Load Cells with High Resolution Indicators, Precision Weights. Verifications traceable to the NIST (National Institute of Standards & Technology), in accordance with A.S.T.M. E74 and E4 latest specifications.

Authorized Instron Corp. Representative:

Instron Corporation - 100 Royall Street - Canton, Massachusetts 02021 - Tel. (617) 828-2500

F148

Tables

Summary of Testing Results for Barsplice Products, Inc.
Model #8XL-2Y (long)

TEST ID#	FAILURE STRESS (ksi)	FAILURE LOAD(kips)	FAILURE STRAIN(%)	GAGE LENGTH(in)
PURESTEEL-MONO1	105.2	82.6	10.7	21.01
Co B - MONO:ORNG1X	104.5	82.5	5.2	21.38
Co B - MONO:ORNG2X	104.7	82.7	9.3	20.97
Co B - STEPCYCLE:ORNG3X	87.0*	110.0*		21.16
Co B - STEPCYCLE:ORNG4X	101.7	80.4	7.4	21.01
Co B - CYCLE4%ORNG5X	103.0	81.4	7.3	21.16
Co B - CYCLE4%:ORNG6X	107.8	85.2	7.8	21.16
125% Nominal	75.0	59.25		

* See written summary

Table 1

Summary of Testing Results for Barsplice Products, Inc.
Model #8XL-2Y(short/part-swagged)

TEST ID#	FAILURE STRESS (ksi)	FAILURE LOAD(kips)	FAILURE STRAIN(%)	GAGE LENGTH(in)
PURESTEEL-MONO1	105.2	82.6	10.7	21.01
Co B - MONO:RED1L	101.5	80.1	7.1	21.26
Co B - MONO:RED3L	105.6	83.4	8.1	21.24
Co B - STEPCYCLE:RED6L	101.0	79.8	8.7	21.08
Co B - STEPCYCLE:RED7L	98.1	77.5	8.5	21.18
Co B - CYCLE4%:RED2L	105.4	83.3	6.6	21.16
Co B - CYCLE4%:RED4L	100.1	79.1	8.2	21.14
125% Nominal	75.0	59.3		

Table 2

Summary of Testing Results for Barsplice Products, Inc.
(Model #8B-2Y)

TEST ID#	FAILURE STRESS (ksi)	FAILURE LOAD(kips)	FAILURE STRAIN(%)	GAGE LENGTH(in)
PURESTEEL-MONO	105.2	82.6	10.7	21.01
Co B - MONOYLW1	102.8	81.2	9.3	20.95
Co B - MONOYLW2	101.4	80.1	7.8	21.16
Co B - MONOYLW3	99.5	78.6	6.0	21.05
Co B - STEPCYCLEYLW4	106.6	84.2	9.4	20.99
Co B - STEPCYCLEYLW5	99.6	78.7	8.9	20.96
Co B - STEPCYCLEYLW6	98.7	78.0	7.2	20.96
Co B - CYCLE4%YLW8	103.3	81.6	8.8	21.01
Co B - CYCLE4%YLW9	103.6	81.8	8.9	21.04
125% Nominal	75	59.25		

Table 3

Figures

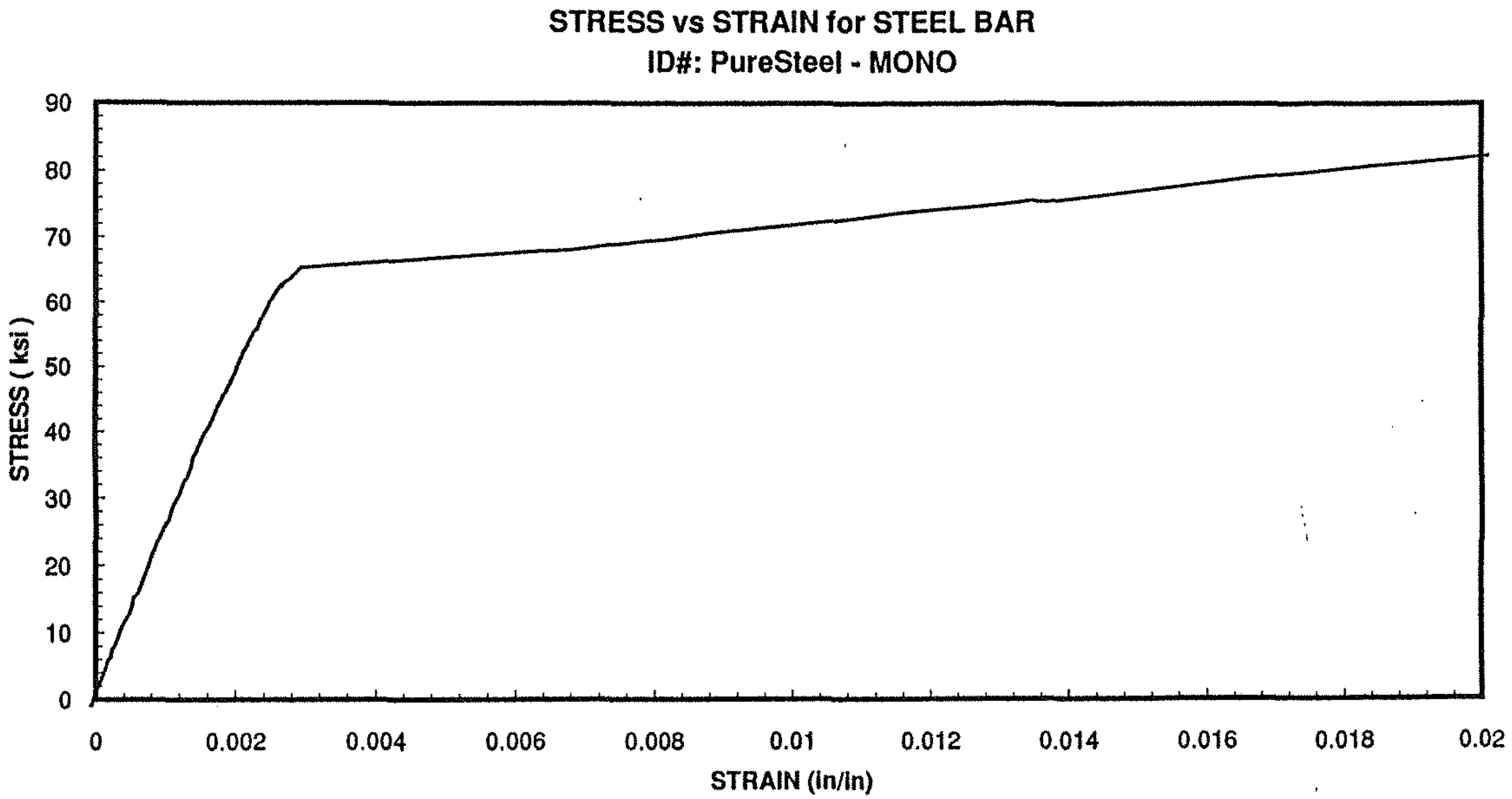

STRESS vs STRAIN for STEEL BAR
ID#: PureSteel - MONO
STRESS (ksi)
90
80
70
60
50
40
30
20
10
0
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
STRAIN (in/in)

Figure 1

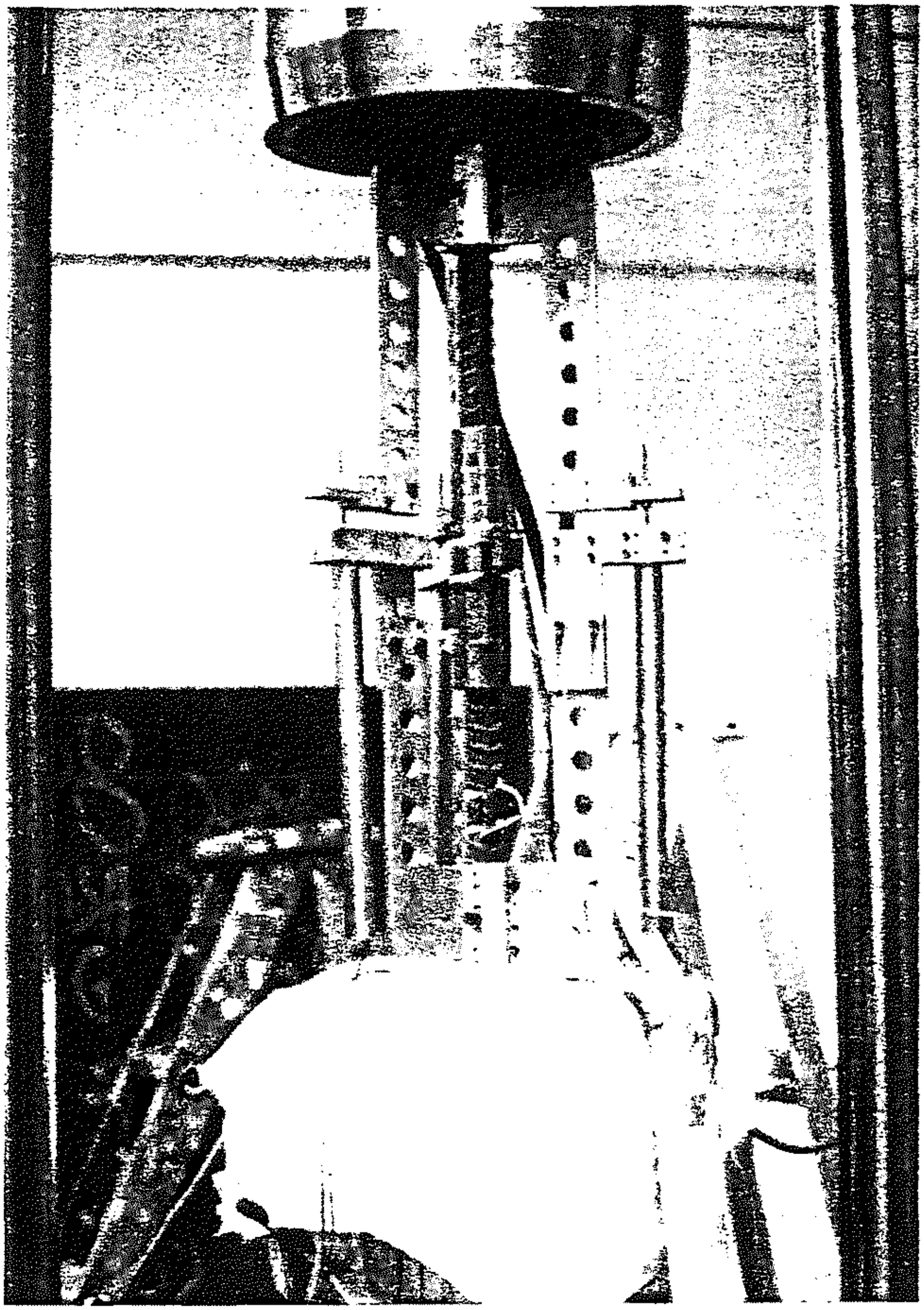


Figure 2

Model 8XL-2Y Bargrip XL Swagged (Orange)

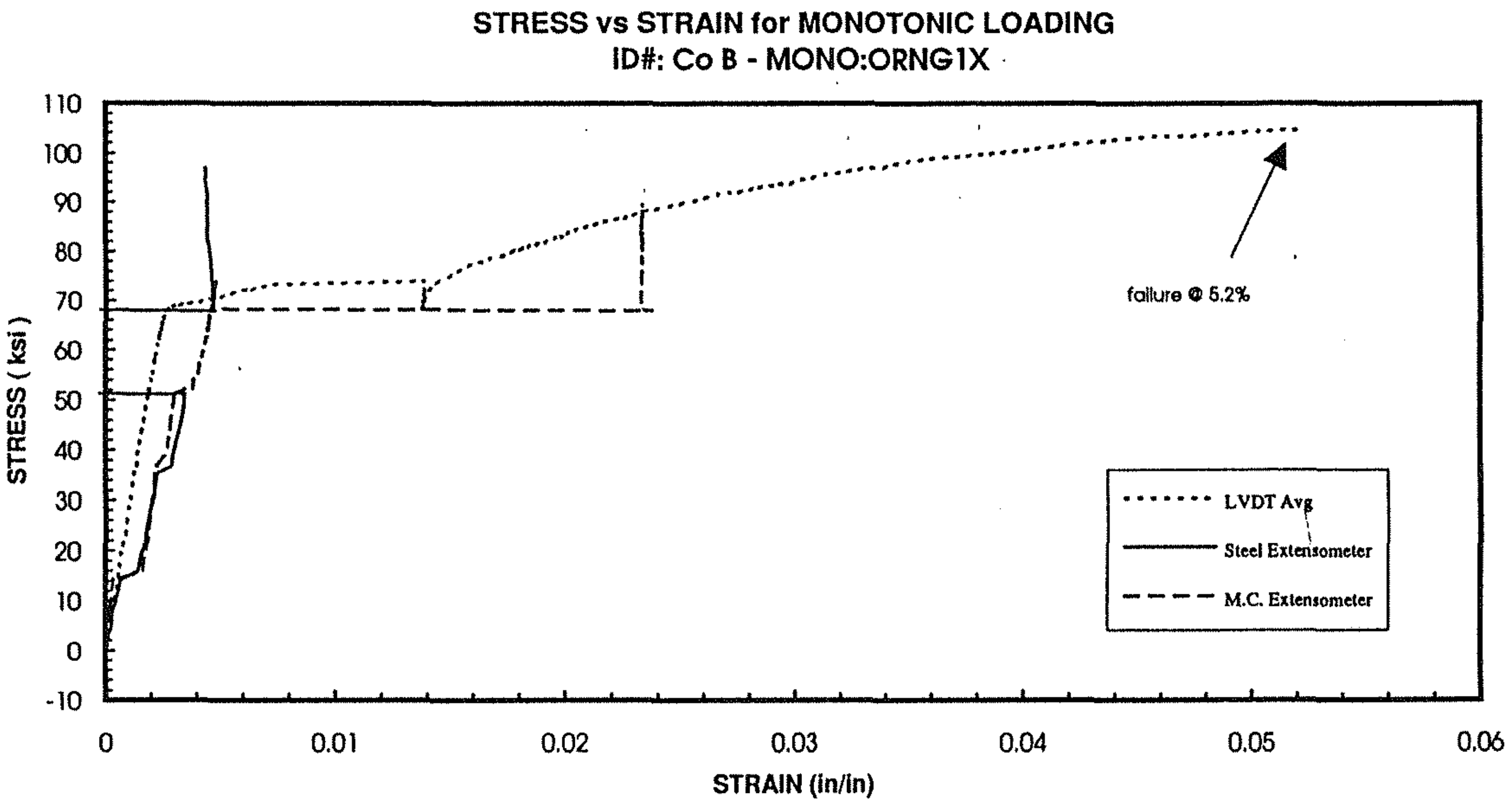

STRESS vs STRAIN for MONOTONIC LOADING
ID#: Co B - MONO:ORNG1X
STRESS (ksi)
110
100
90
80
70
60
50
40
30
20
10
0
-10
0
0.01
0.02
0.03
0.04
0.05
0.06
STRAIN (in/in)
failure @ 5.2%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 3a

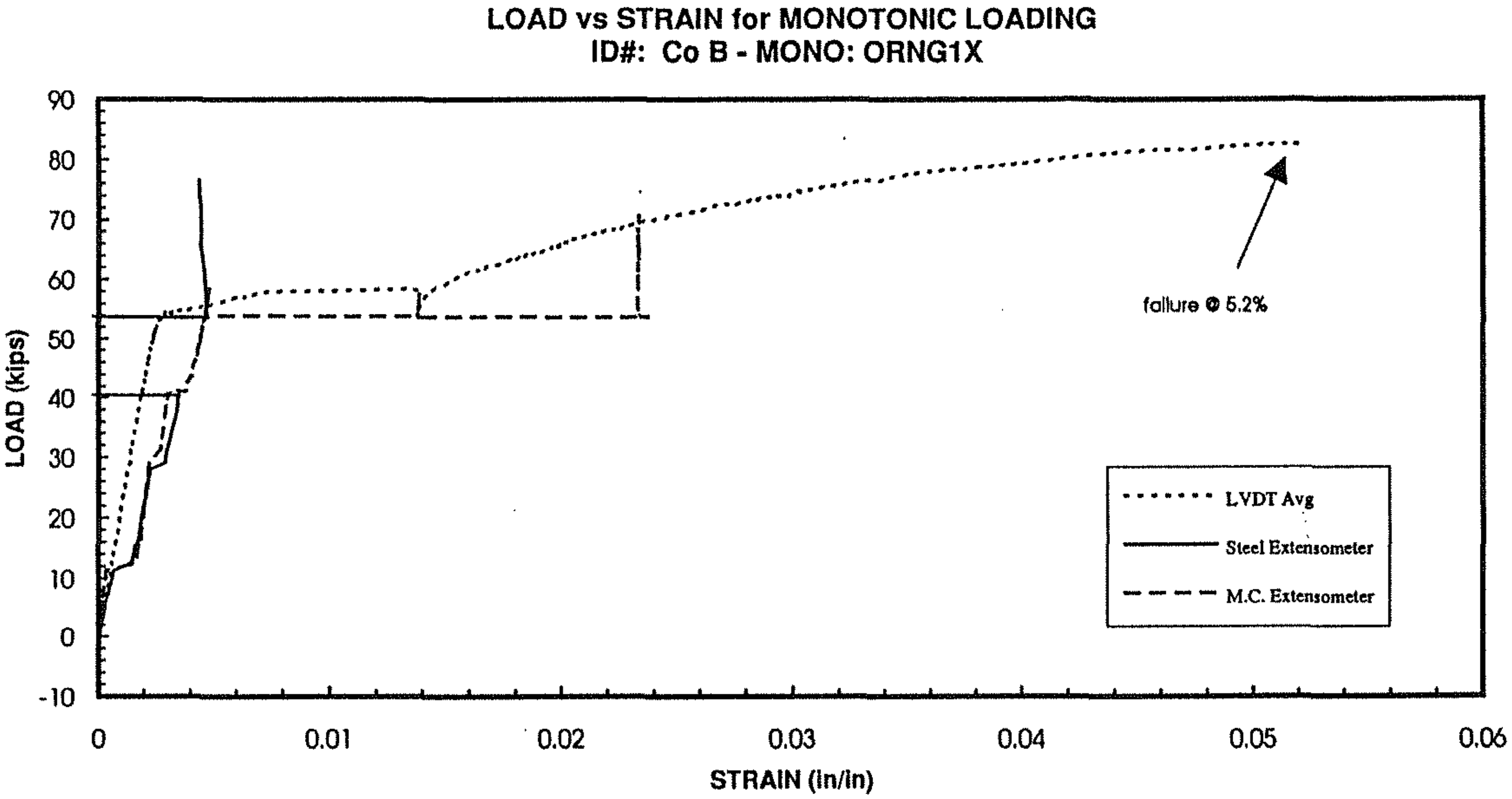

LOAD vs STRAIN for MONOTONIC LOADING
ID#: Co B - MONO: ORNG1X
90
80
70
60
50
40
30
20
10
0
-10
LOAD (kips)
0
0.01
0.02
0.03
0.04
0.05
0.06
STRAIN (in/in)
failure @ 5.2%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 3b

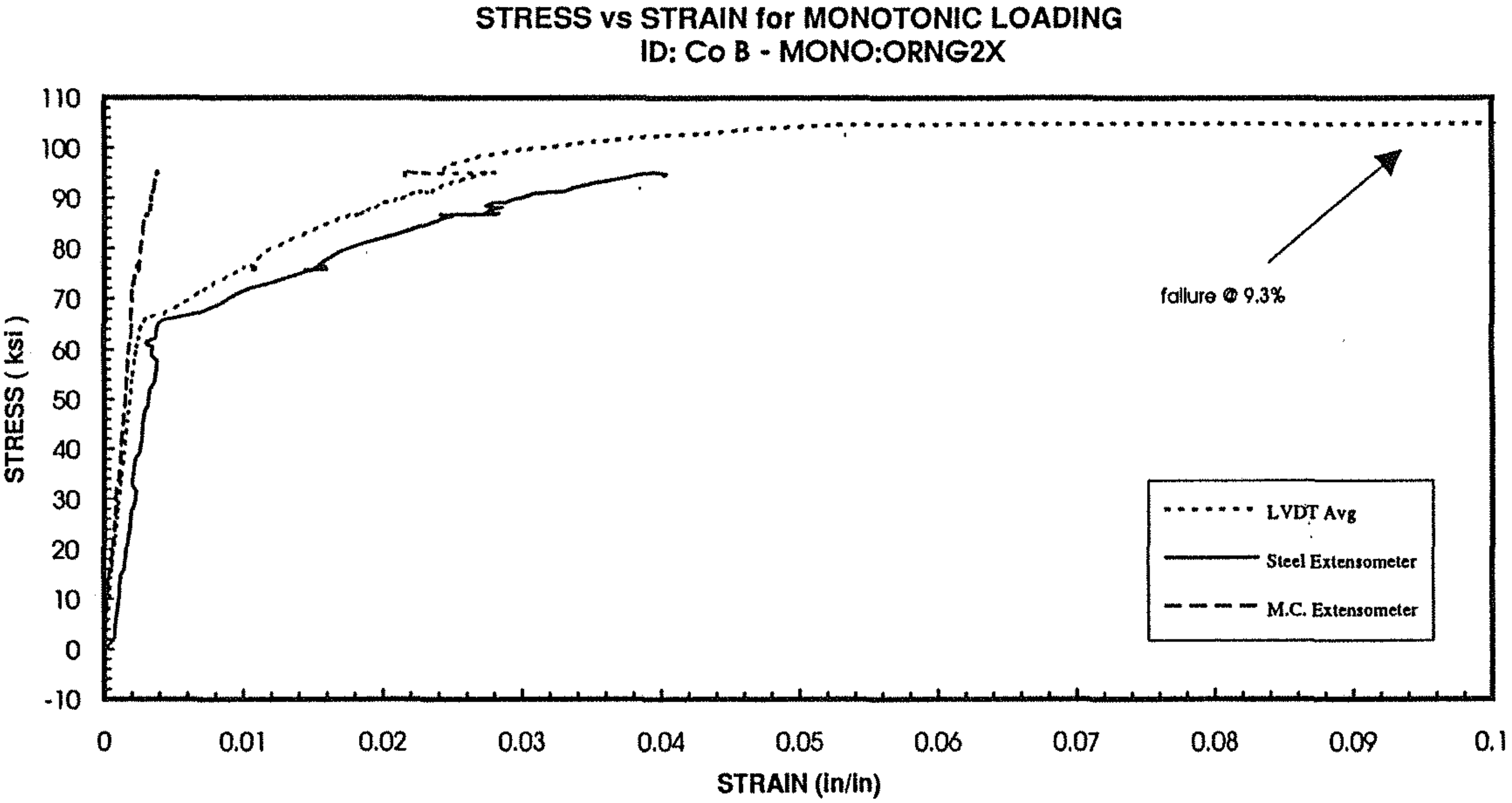

STRESS vs STRAIN for MONOTONIC LOADING
ID: Co B - MONO:ORNG2X
STRESS (ksi)
110
100
90
80
70
60
50
40
30
20
10
0
-10
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
STRAIN (in/in)
failure @ 9.3%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 4a

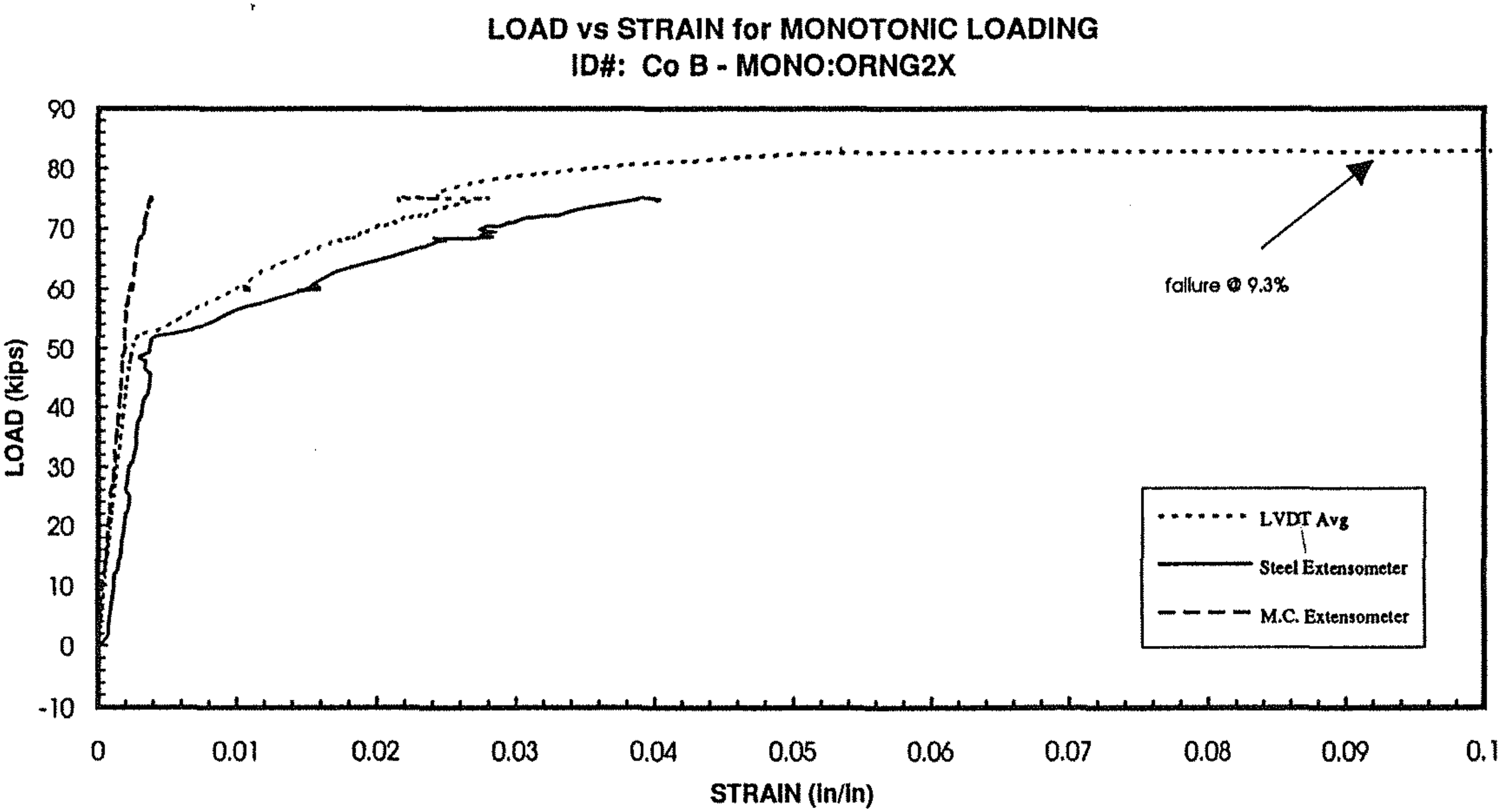

LOAD vs STRAIN for MONOTONIC LOADING
ID#: Co B - MONO:ORNG2X
LOAD (kips)
90
80
70
60
50
40
30
20
10
0
-10
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
STRAIN (in/in)
failure @ 9.3%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 4b

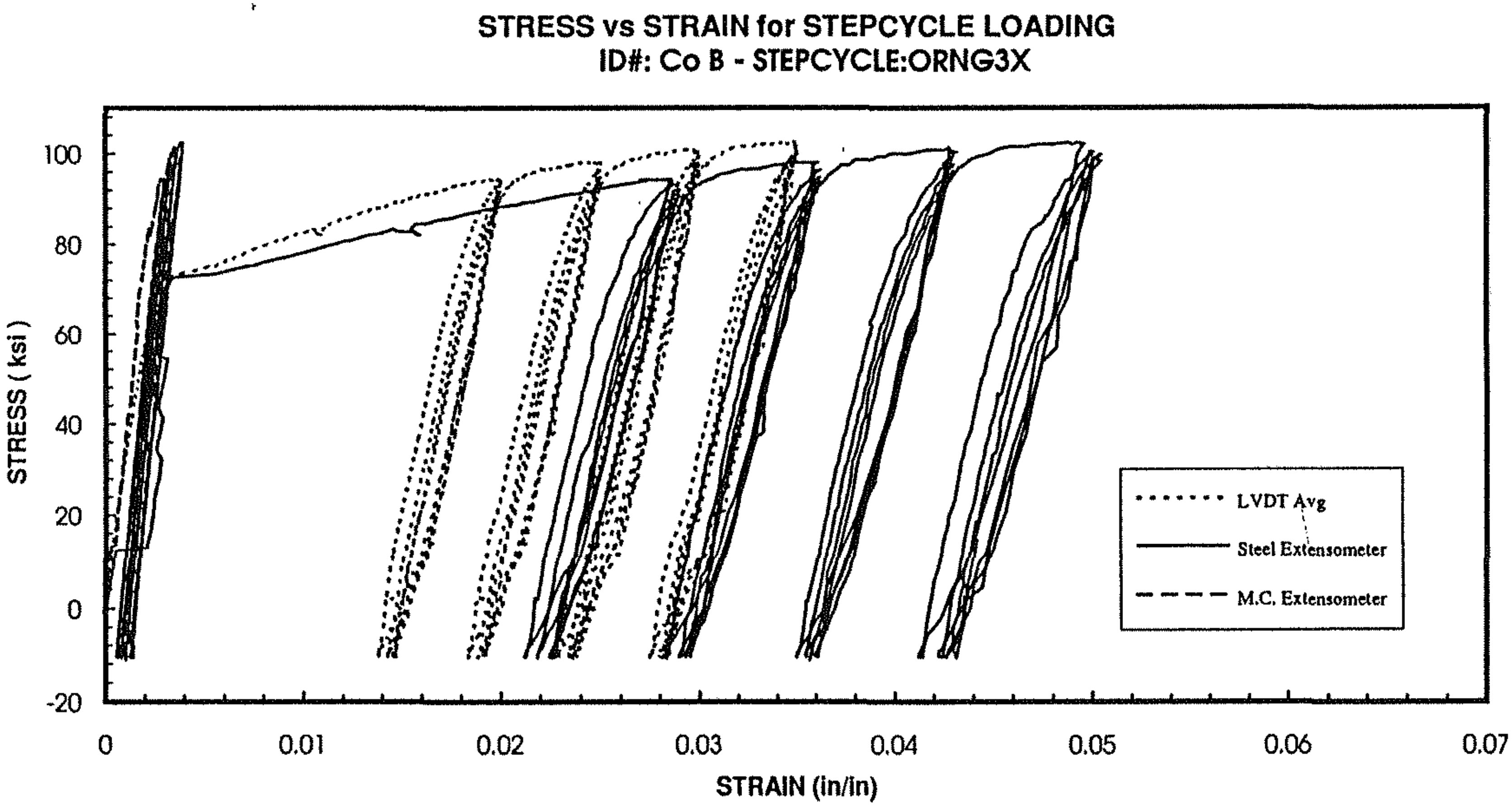

STRESS vs STRAIN for STEPCYCLE LOADING
ID#: Co B - STEPCYCLE:ORNG3X
STRESS (ksi)
100
80
60
40
20
0
-20
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
STRAIN (in/in)
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 5a

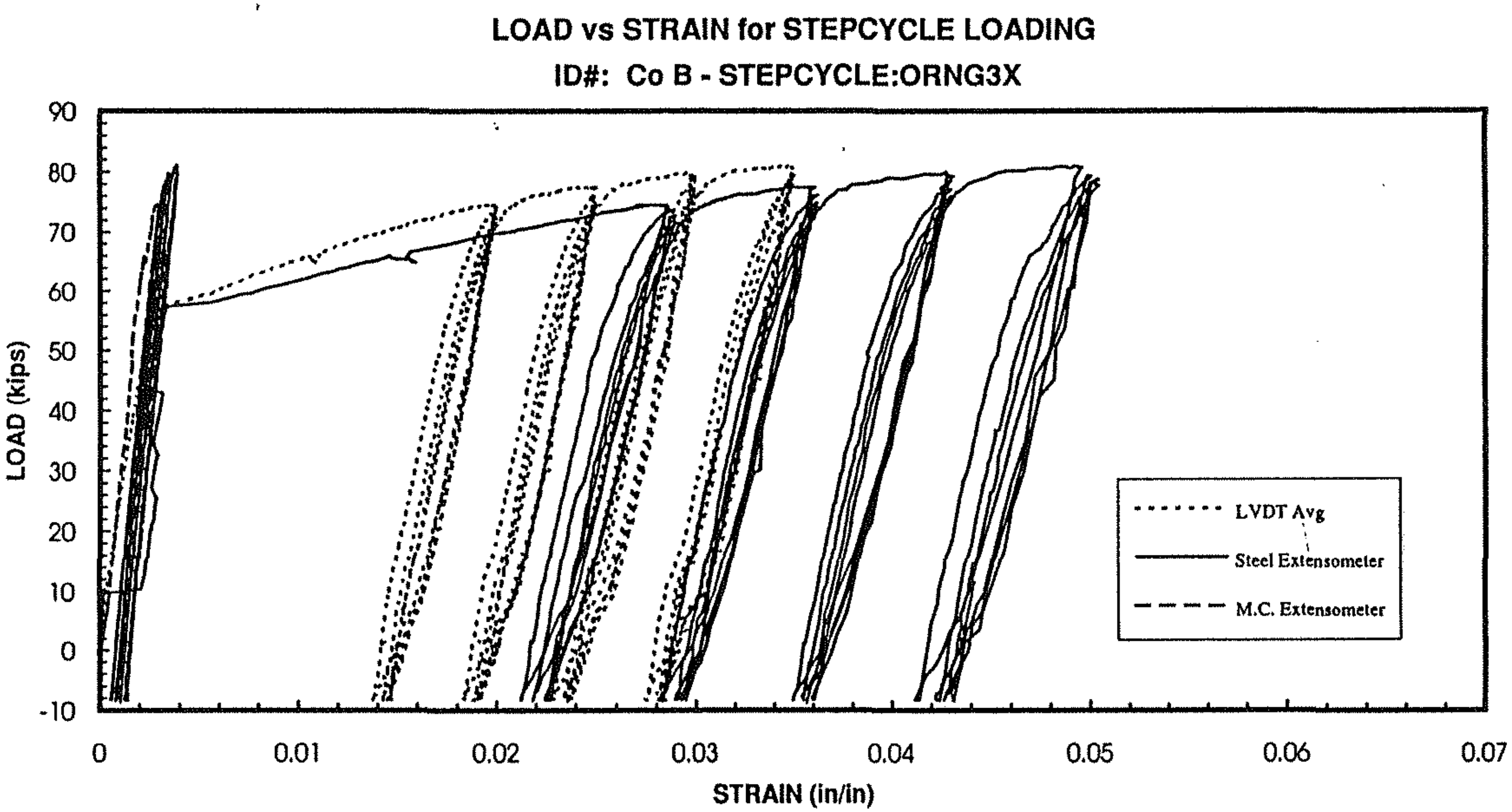

LOAD vs STRAIN for STEPCYCLE LOADING
ID#: Co B - STEPCYCLE:ORNG3X
LOAD (kips)
90
80
70
60
50
40
30
20
10
0
-10
STRAIN (in/in)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 5b

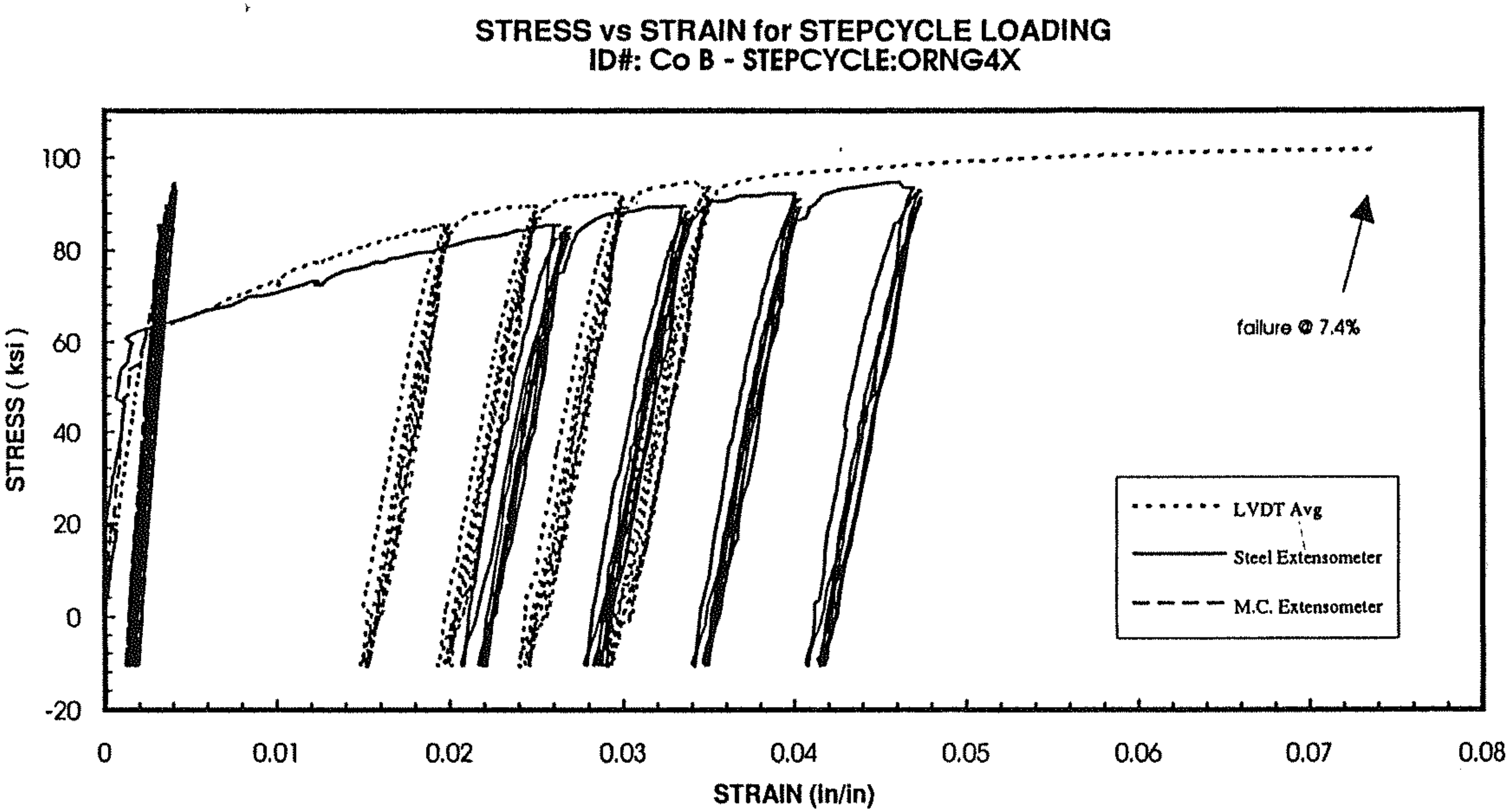

STRESS vs STRAIN for STEPCYCLE LOADING
ID#: Co B - STEPCYCLE:ORNG4X
STRESS (ksi)
100
80
60
40
20
0
-20
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
STRAIN (in/in)
failure @ 7.4%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 6a

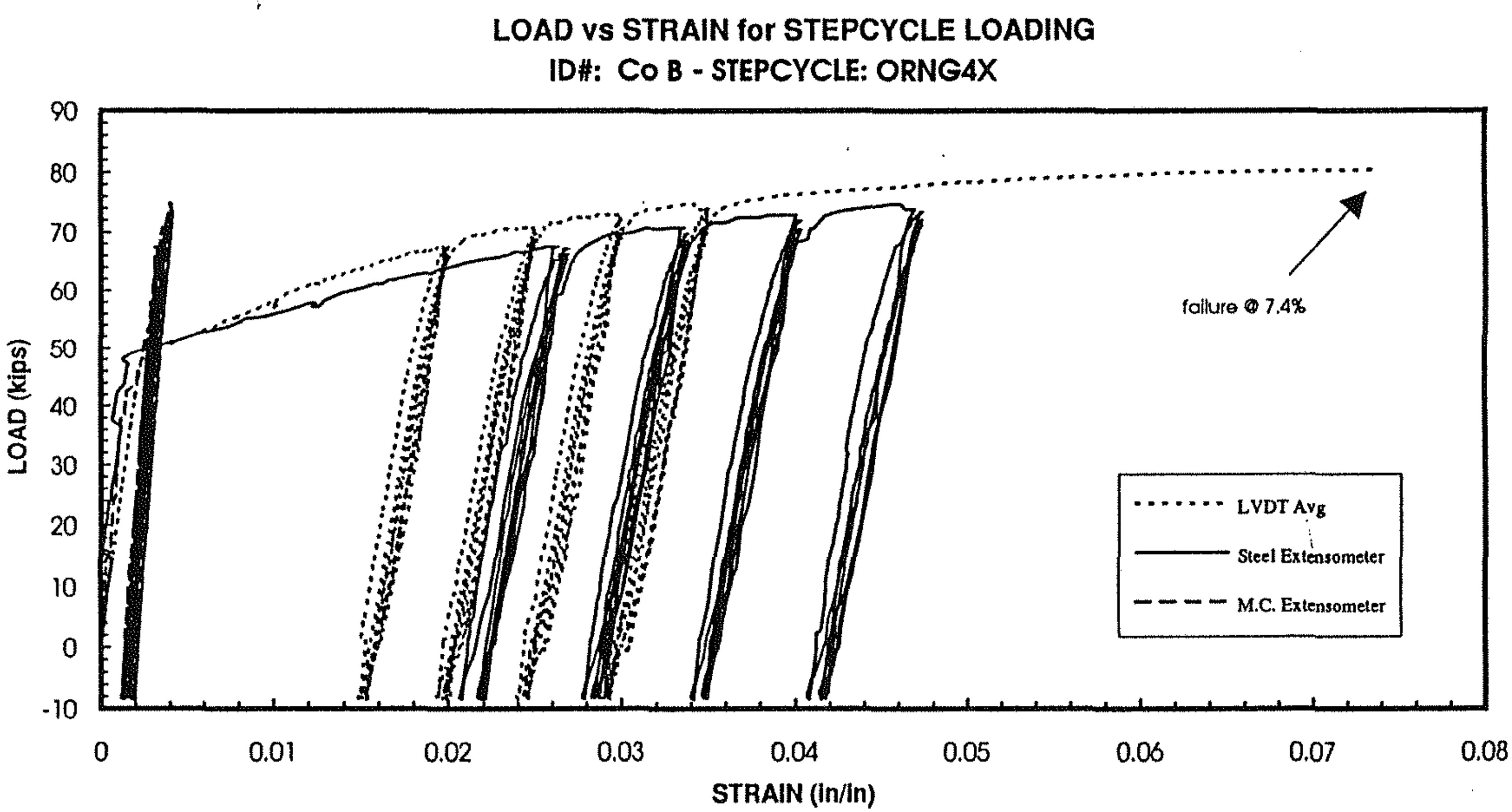

LOAD vs STRAIN for STEPCYCLE LOADING
ID#: Co B - STEPCYCLE: ORNG4X
LOAD (kips)
90
80
70
60
50
40
30
20
10
0
-10
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
STRAIN (in/in)
failure @ 7.4%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 6b

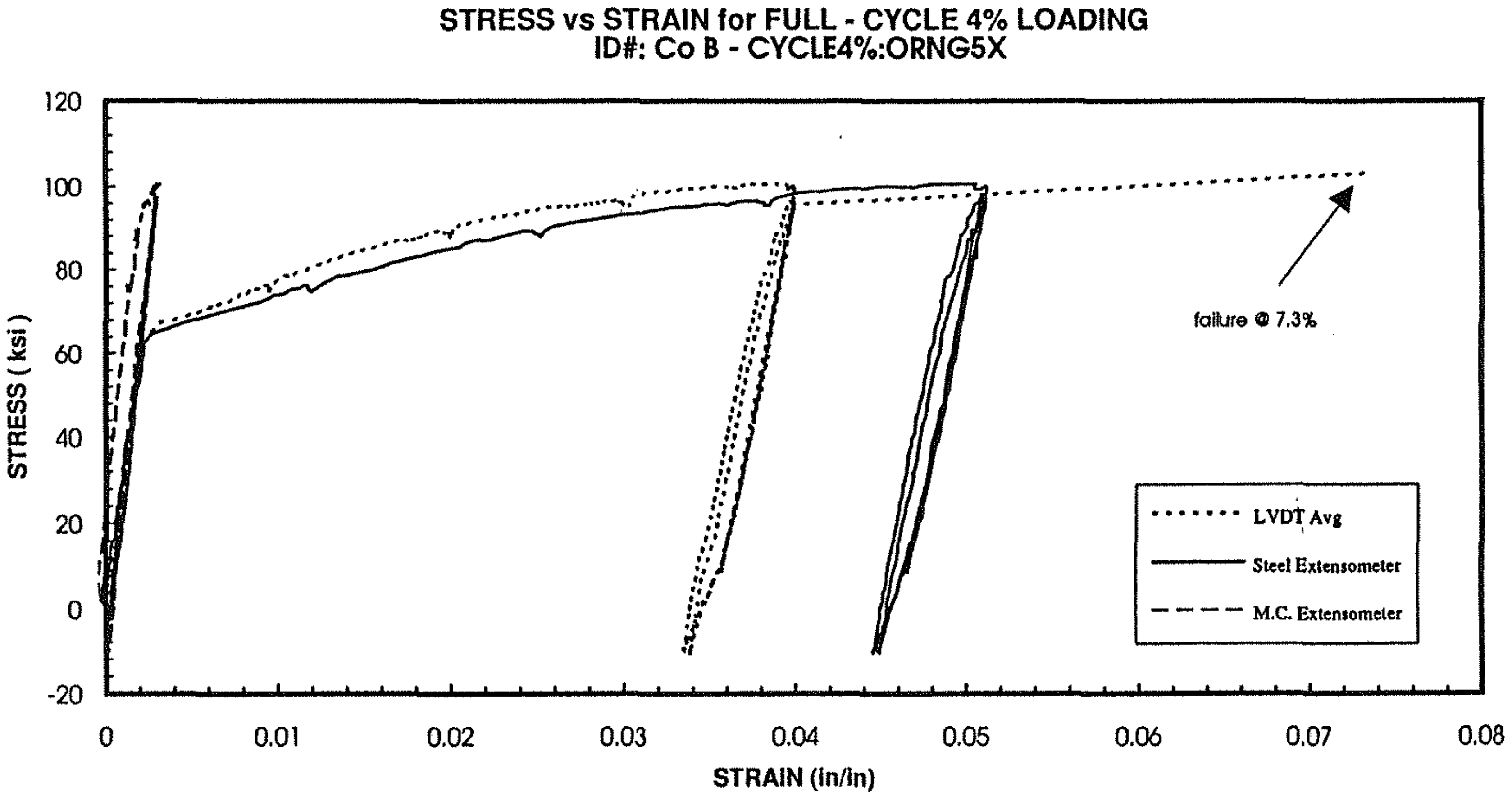

STRESS vs STRAIN for FULL - CYCLE 4% LOADING
ID#: Co B - CYCLE4%:ORNG5X
STRESS (ksi)
120
100
80
60
40
20
0
-20
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
STRAIN (in/in)
failure @ 7.3%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 7a

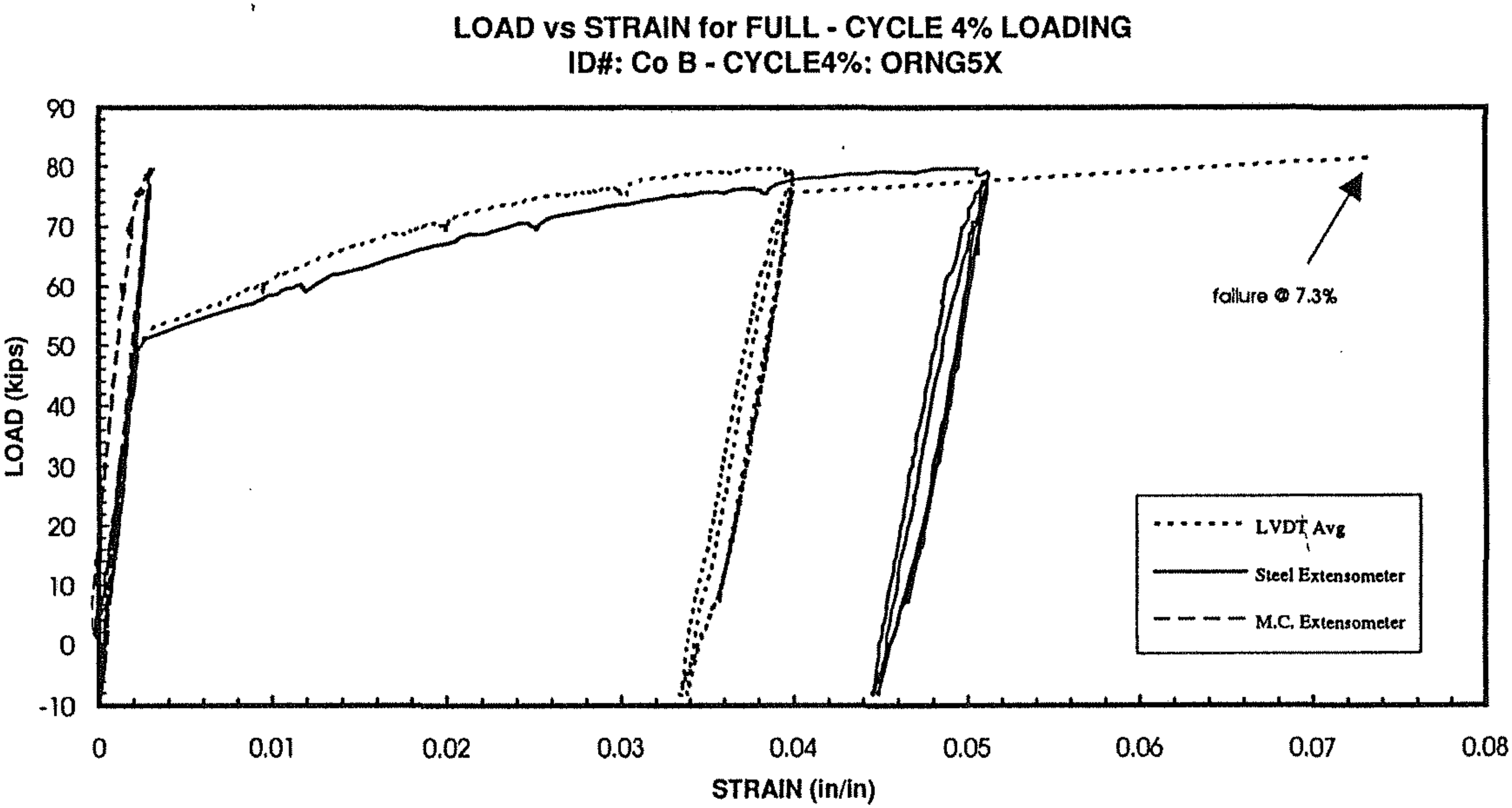

LOAD vs STRAIN for FULL - CYCLE 4% LOADING
ID#: Co B - CYCLE4%: ORNG5X
LOAD (kips)
90
80
70
60
50
40
30
20
10
0
-10
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
STRAIN (in/in)
failure @ 7.3%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 7b

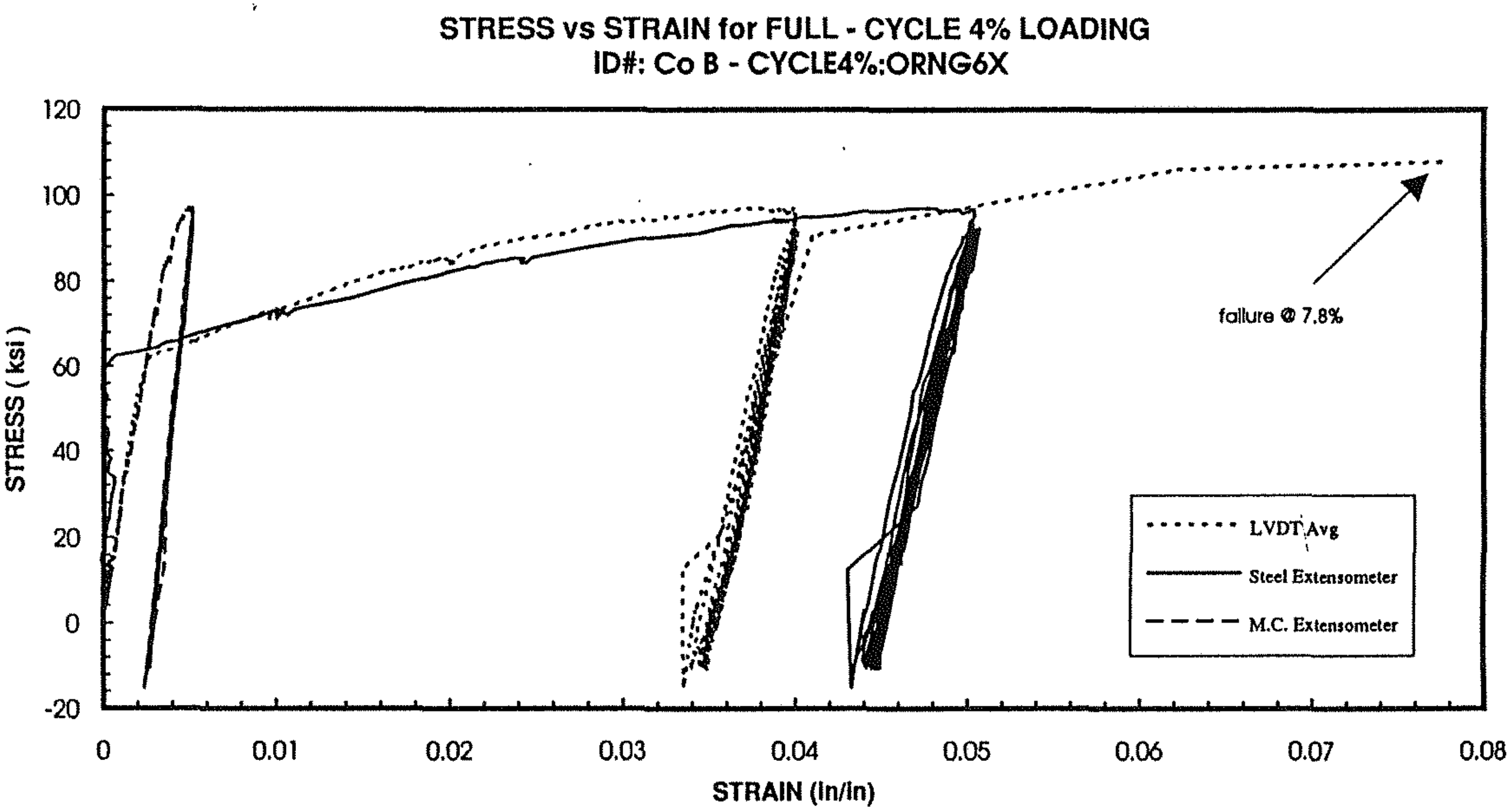

STRESS vs STRAIN for FULL - CYCLE 4% LOADING
ID#: Co B - CYCLE4%:ORNG6X
STRESS (ksi)
STRAIN (in/in)
120
100
80
60
40
20
0
-20
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
failure @ 7.8%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 8a

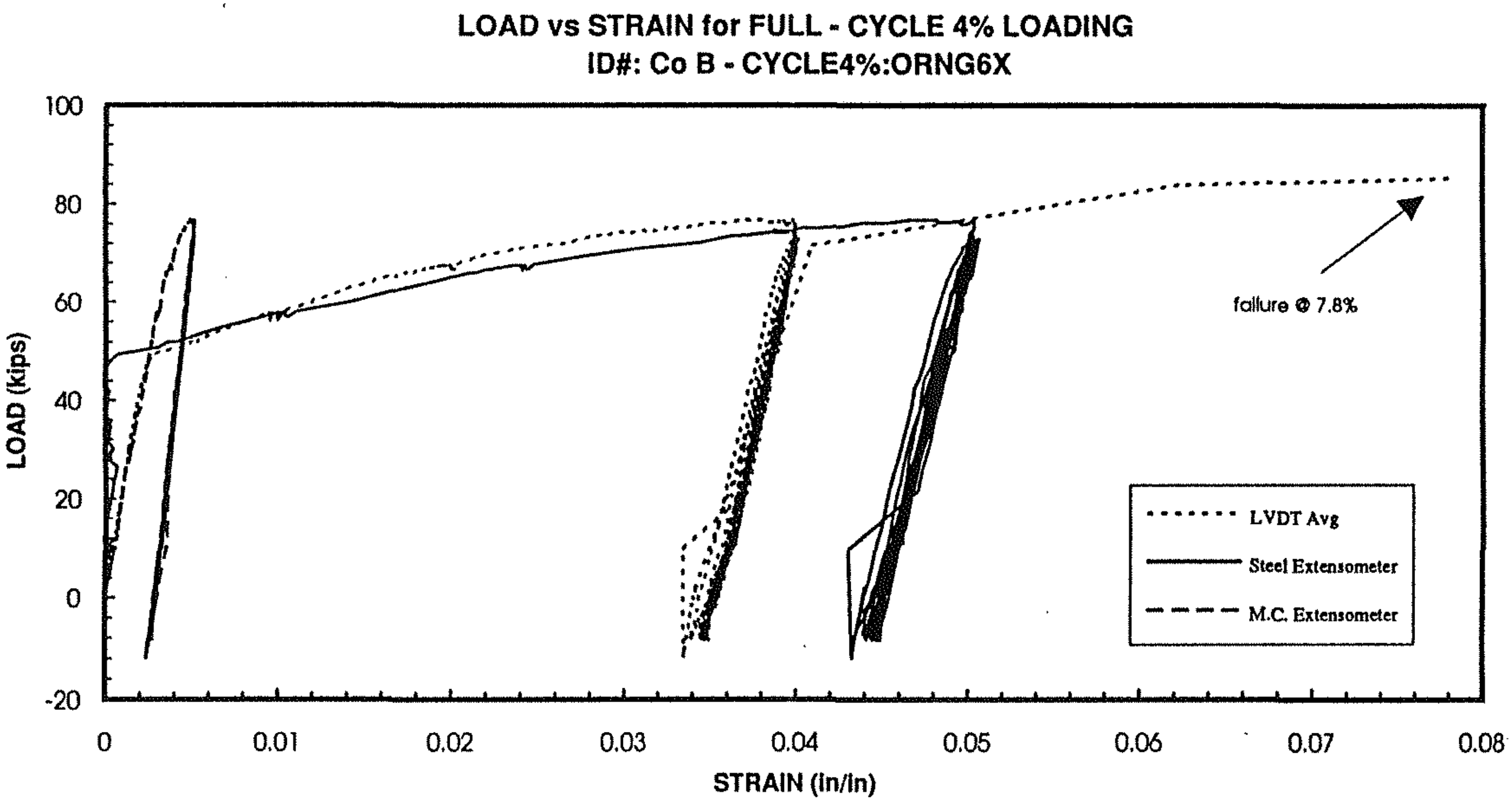

LOAD vs STRAIN for FULL - CYCLE 4% LOADING
ID#: Co B - CYCLE4%:ORNG6X
LOAD (kips)
100
80
60
40
20
0
-20
STRAIN (in/in)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
failure @ 7.8%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 8b

Model 8XL-2Y Bargrip XL Part Swagged (Red)

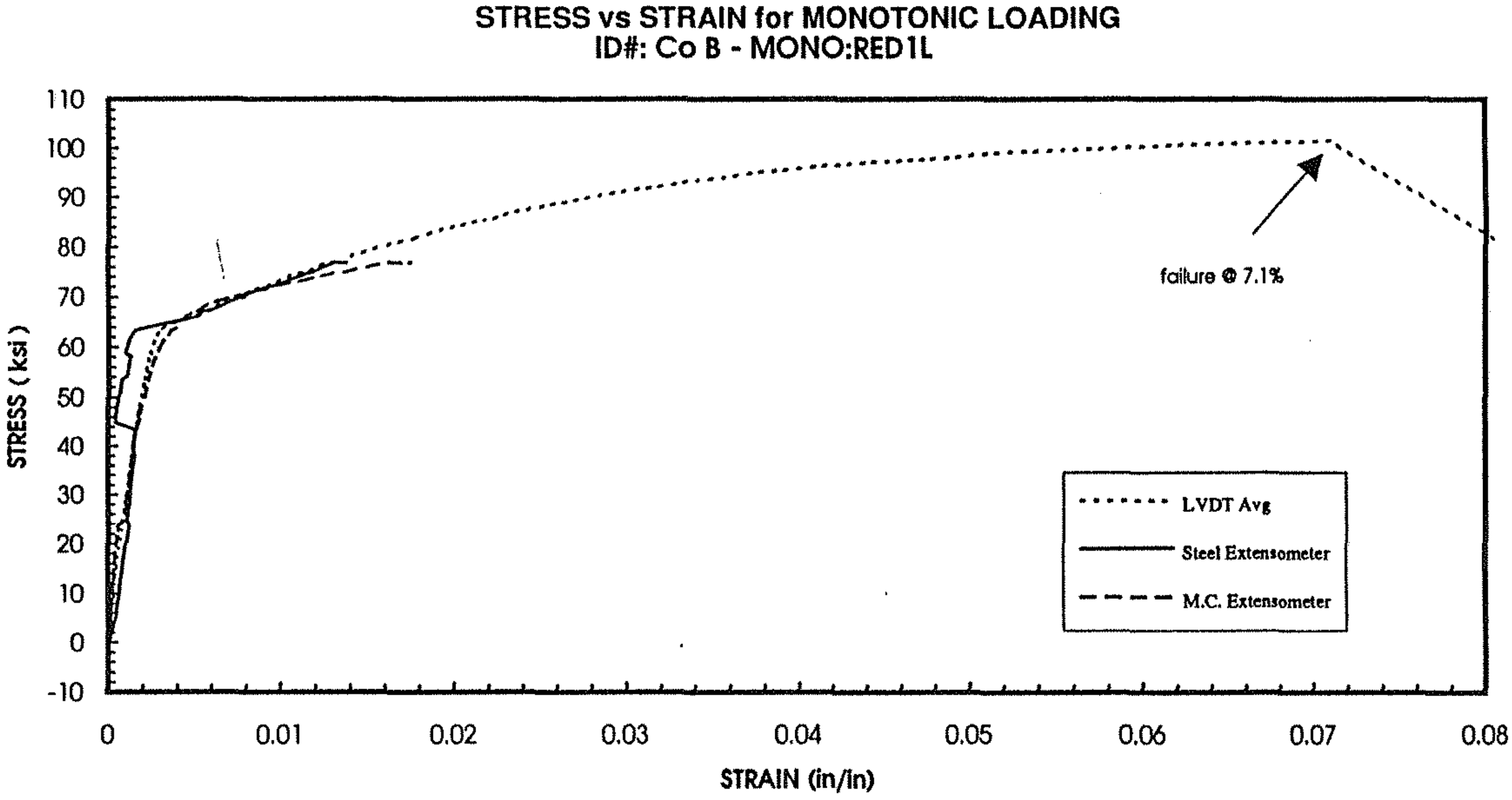
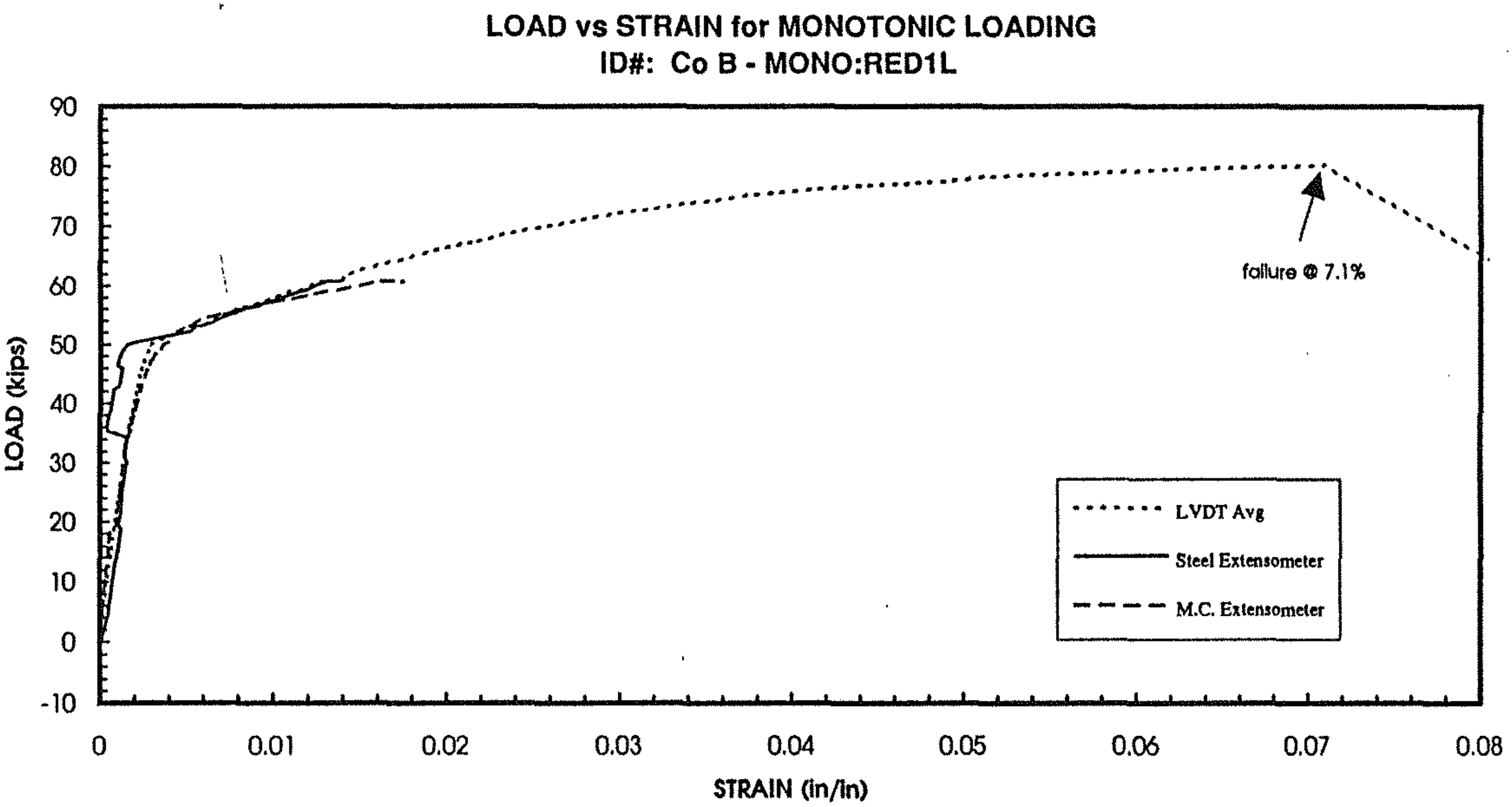

STRESS vs STRAIN for MONOTONIC LOADING
ID#: Co B - MONO:RED1L
STRESS (ksi)
110
100
90
80
70
60
50
40
30
20
10
0
-10
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
STRAIN (in/in)
failure @ 7.1%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 9a



LOAD vs STRAIN for MONOTONIC LOADING
ID#: Co B - MONO:RED1L

Figure 9b

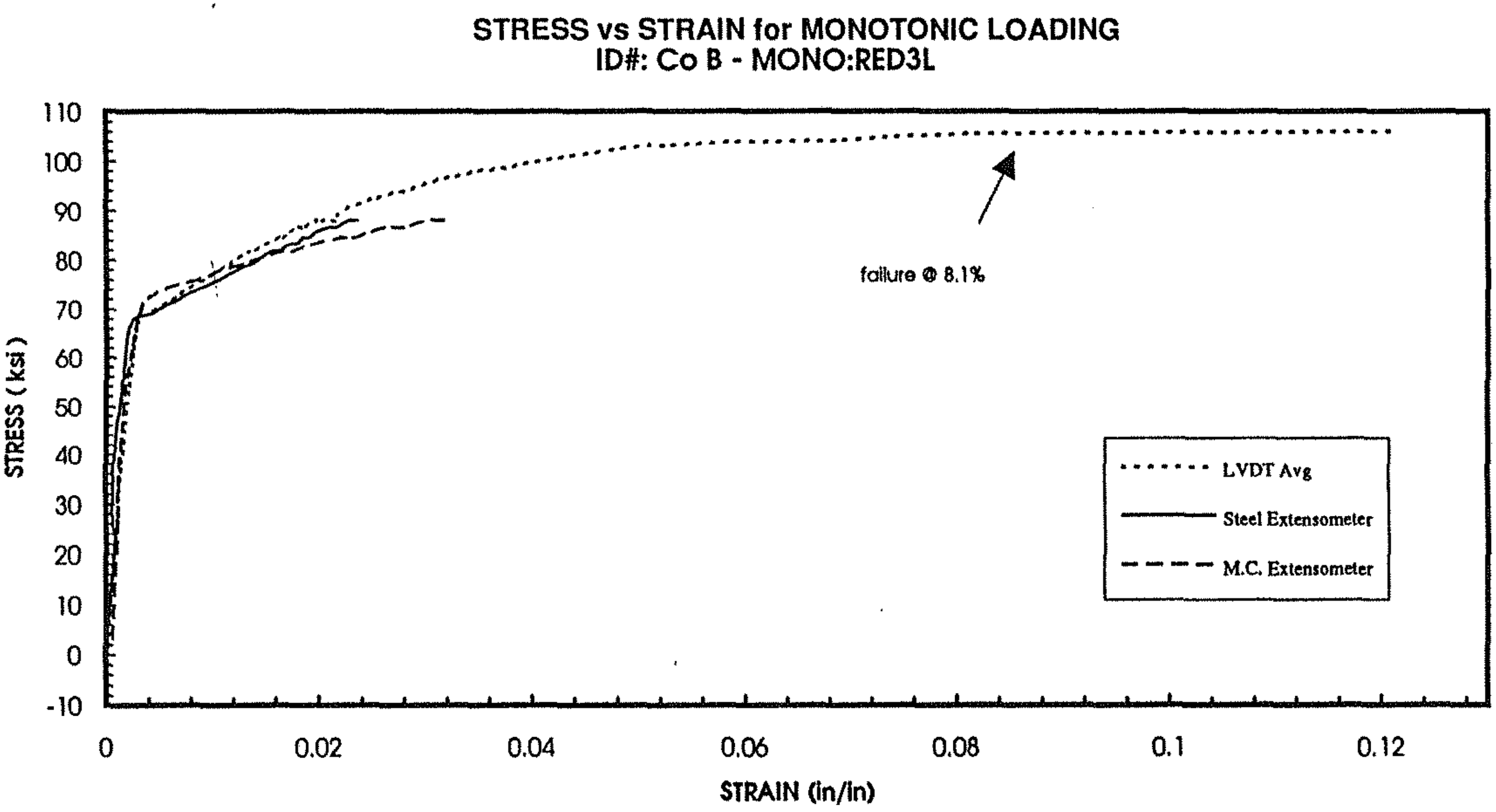

STRESS vs STRAIN for MONOTONIC LOADING
ID#: Co B - MONO:RED3L
STRESS (ksi)
110
100
90
80
70
60
50
40
30
20
10
0
-10
0
0.02
0.04
0.06
0.08
0.1
0.12
STRAIN (in/in)
failure @ 8.1%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 10a

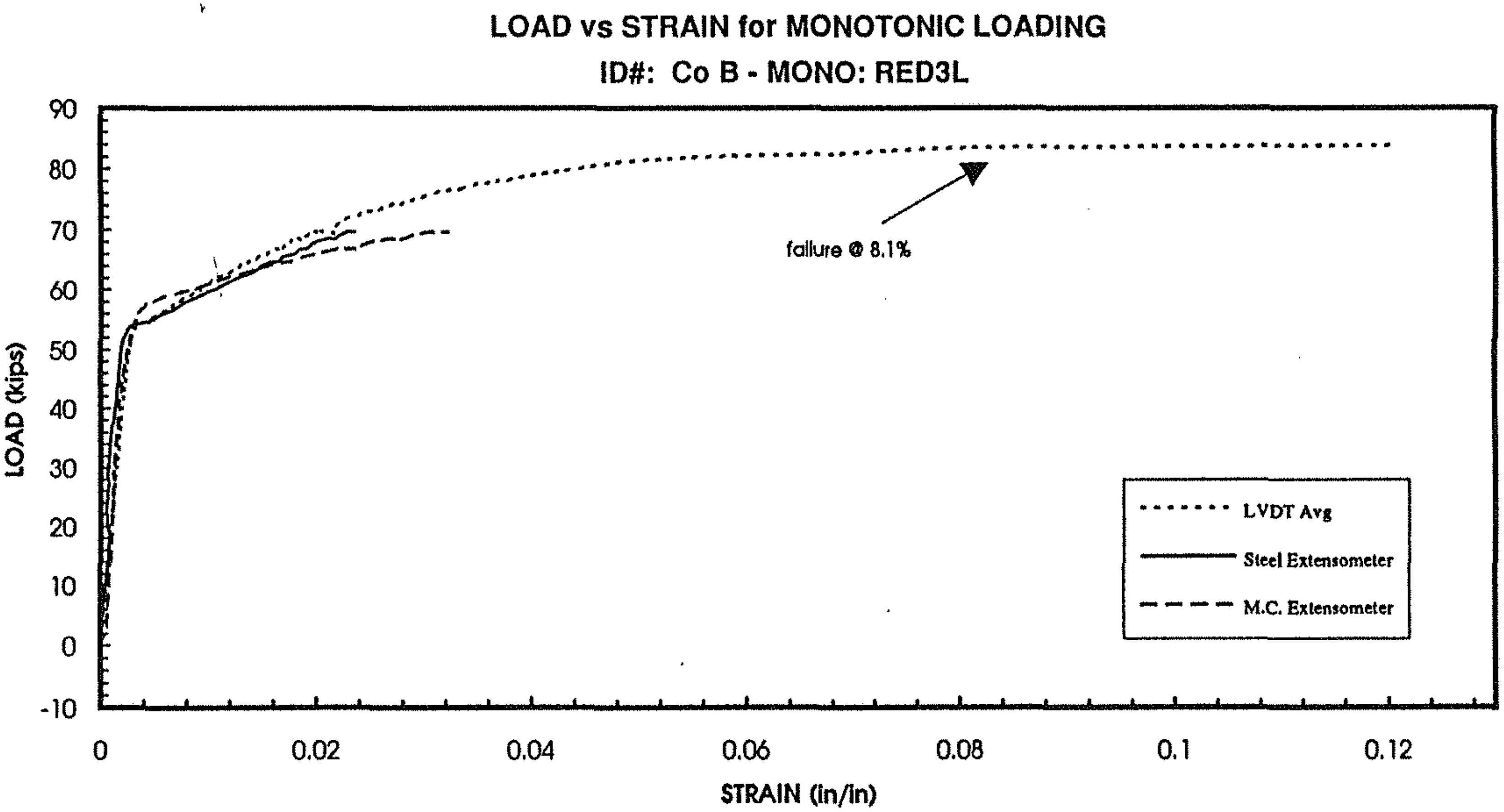
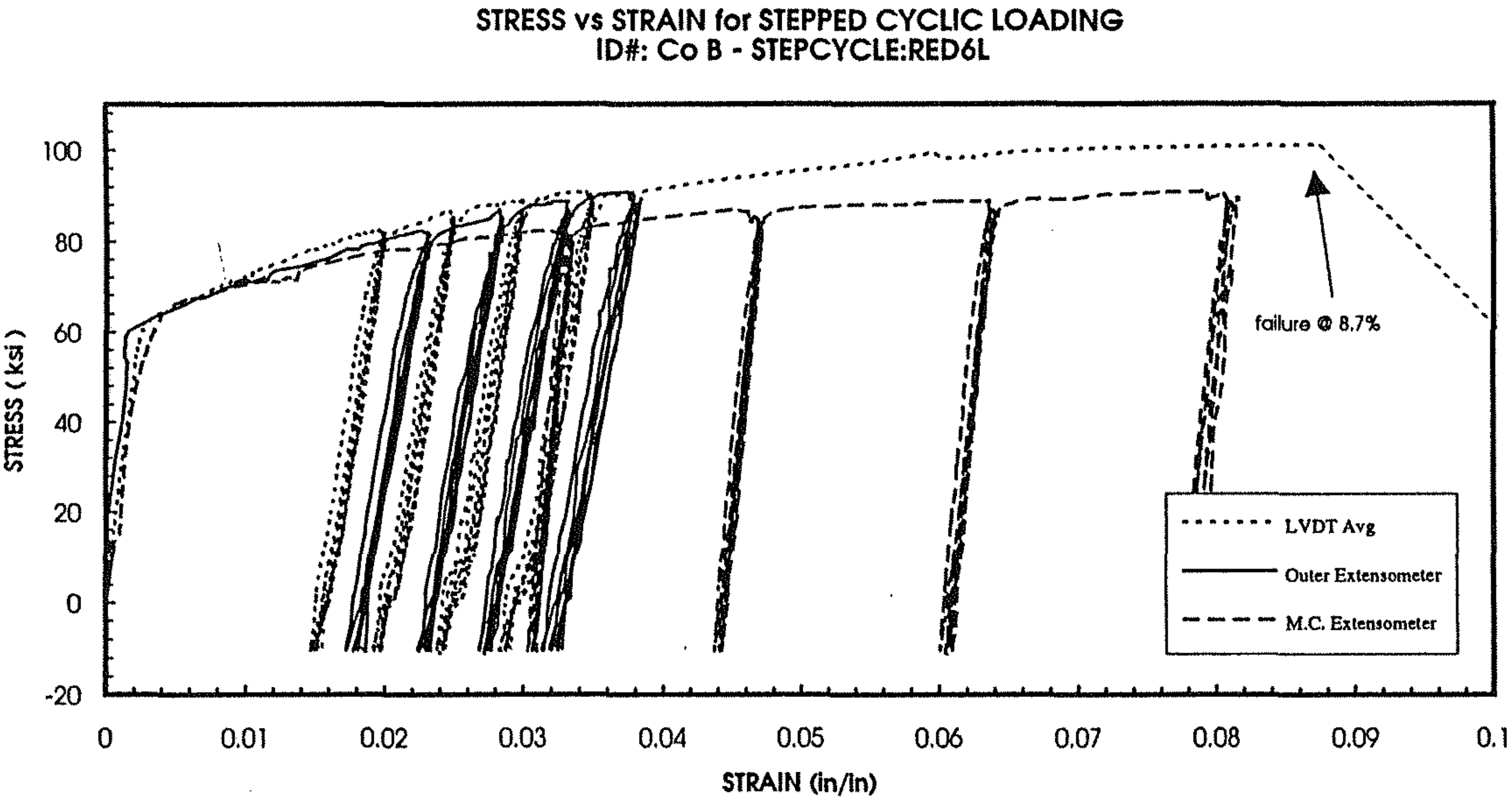

LOAD vs STRAIN for MONOTONIC LOADING
ID#: Co B - MONO: RED3L
LOAD (kips)
90
80
70
60
50
40
30
20
10
0
-10
STRAIN (in/in)
0
0.02
0.04
0.06
0.08
0.1
0.12
failure @ 8.1%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 10b



STRESS vs STRAIN for STEPPED CYCLIC LOADING
ID#: Co B - STEPCYCLE:RED6L

Figure 11a

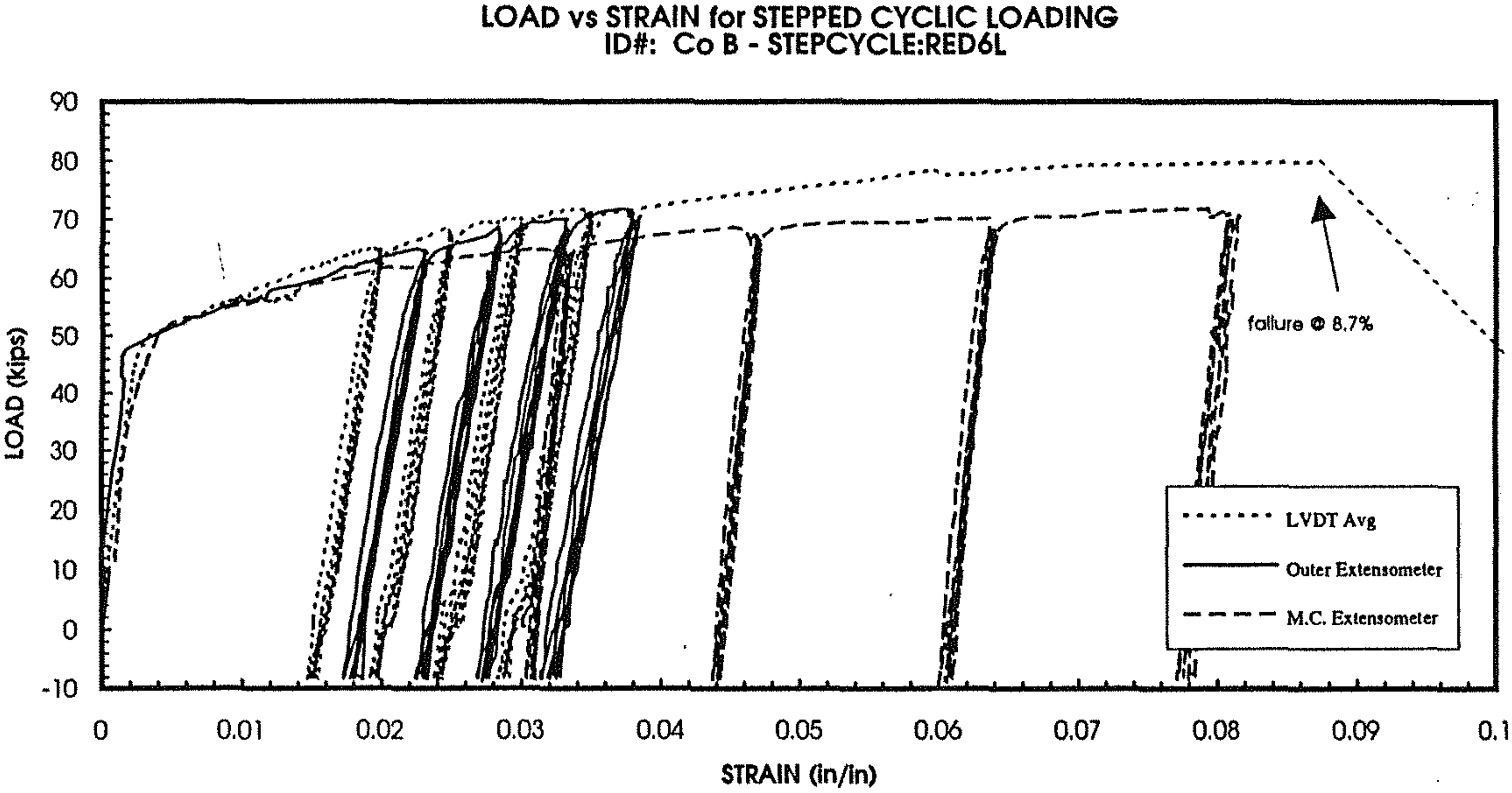
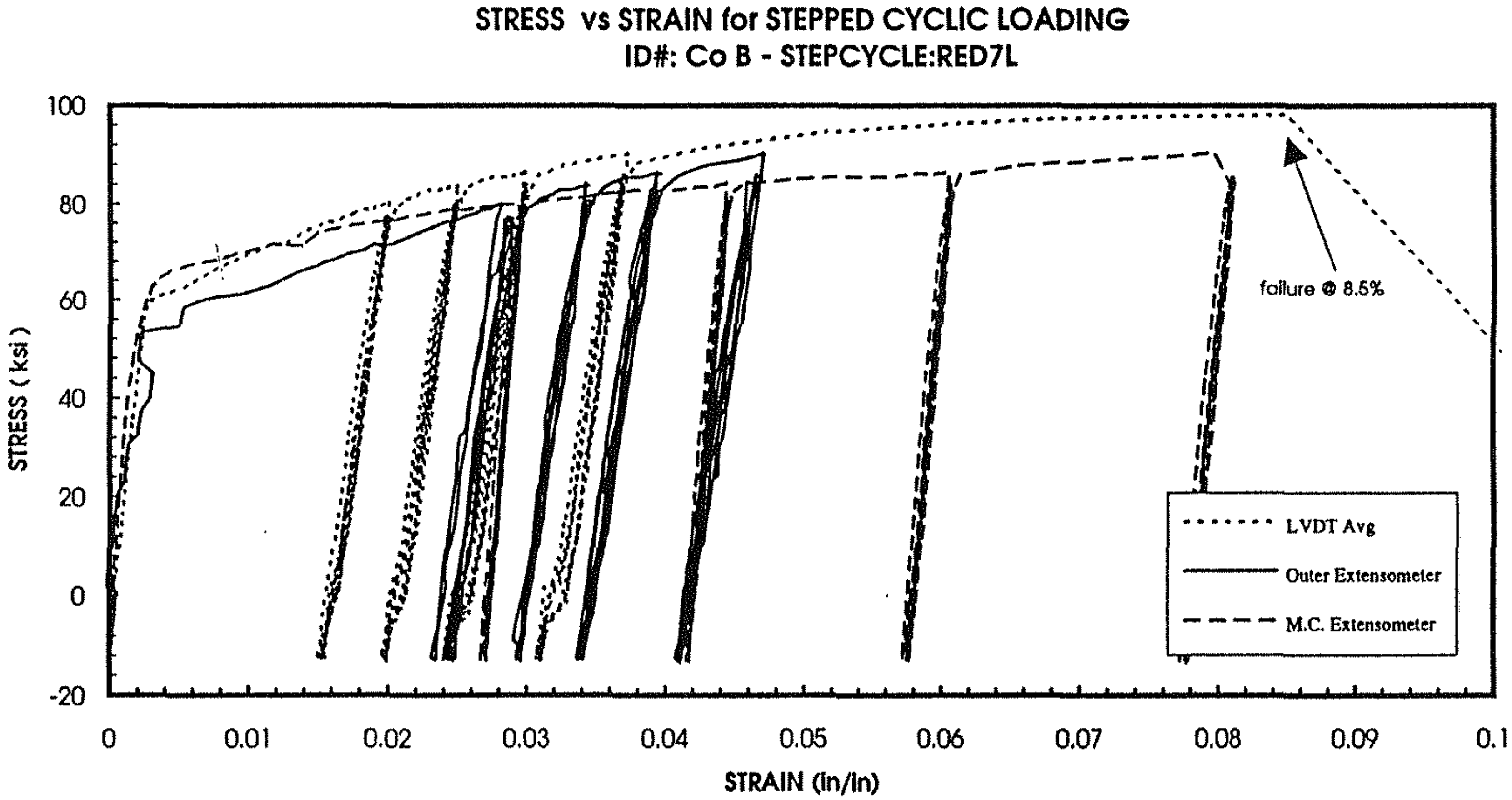

LOAD vs STRAIN for STEPPED CYCLIC LOADING
ID#: Co B - STEPCYCLE:RED6L
LOAD (Kips)
90
80
70
60
50
40
30
20
10
0
-10
STRAIN (in/in)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
failure @ 8.7%
LVDT Avg
Outer Extensometer
M.C. Extensometer

Figure 11b



STRESS vs STRAIN for STEPPED CYCLIC LOADING
ID#: Co B - STEPCYCLE:RED7L

Figure 12a

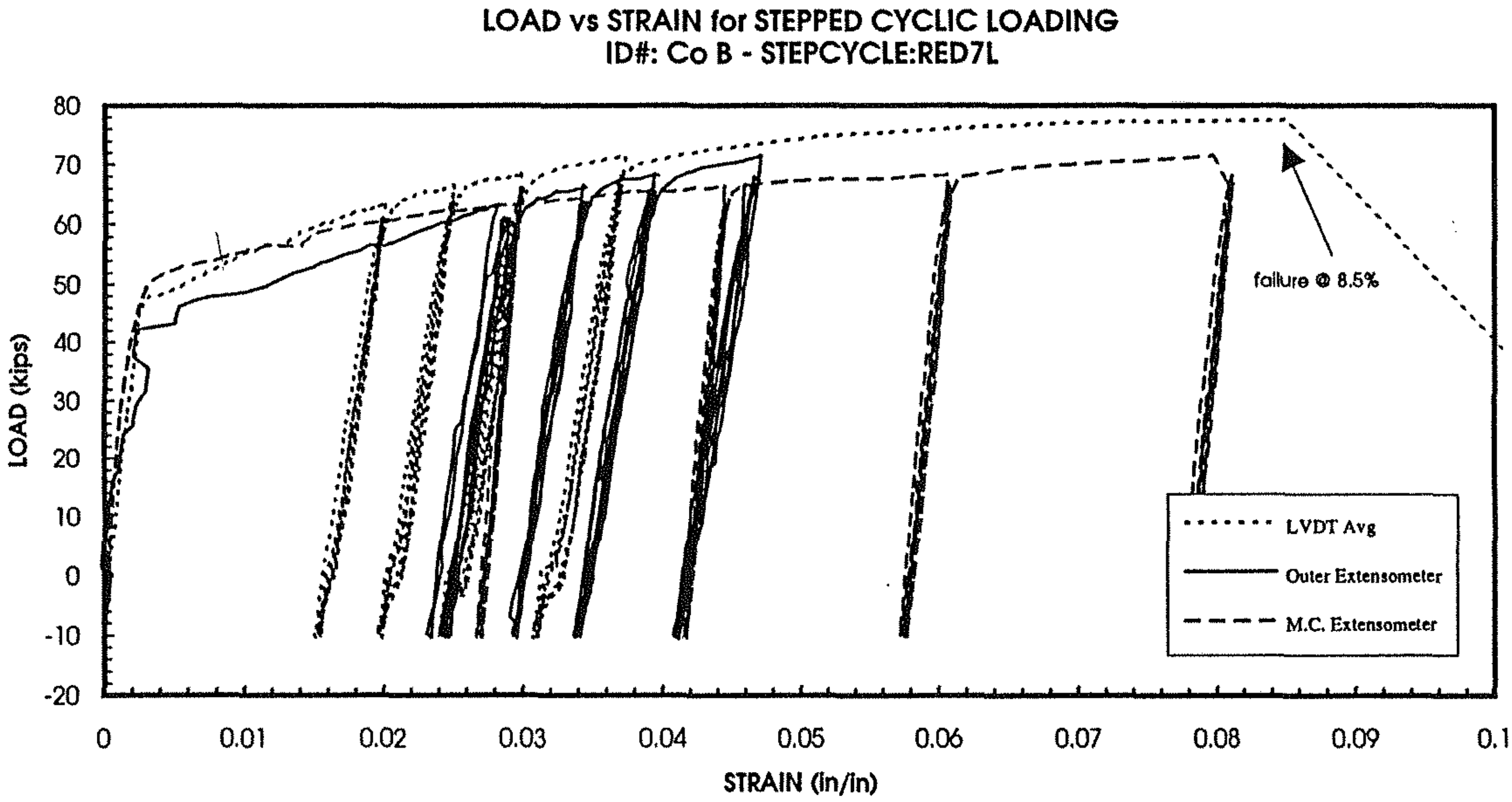

LOAD vs STRAIN for STEPPED CYCLIC LOADING
ID#: Co B - STEPCYCLE:RED7L
LOAD (kips)
80
70
60
50
40
30
20
10
0
-10
-20
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
STRAIN (in/in)
failure @ 8.5%
LVDT Avg
Outer Extensometer
M.C. Extensometer

Figure 12b

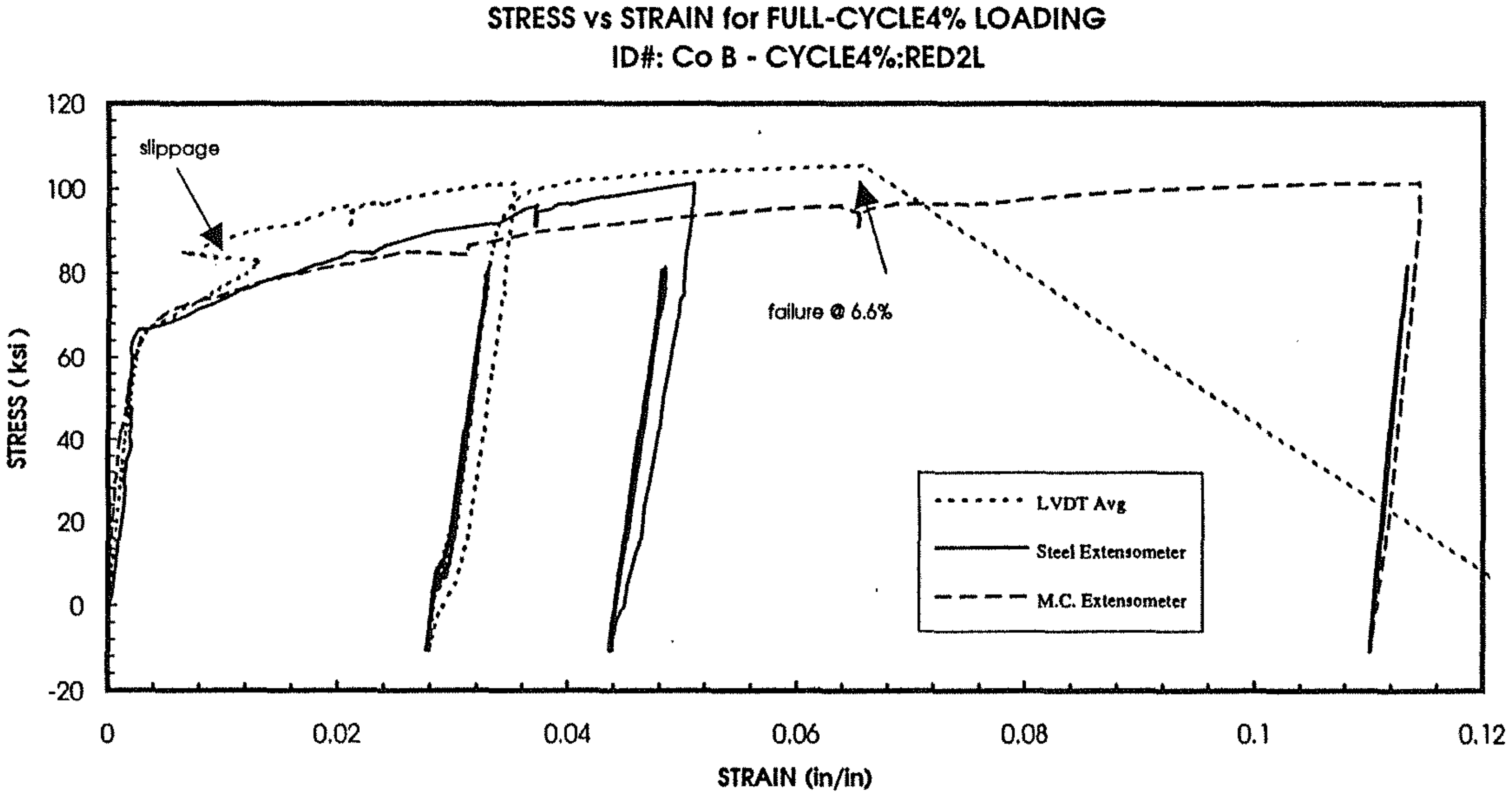

STRESS vs STRAIN for FULL-CYCLE4% LOADING
ID#: Co B - CYCLE4%:RED2L
120
100
80
60
40
20
0
-20
STRESS (ksi)
0
0.02
0.04
0.06
0.08
0.1
0.12
STRAIN (in/in)
slippage
failure @ 6.6%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 13a

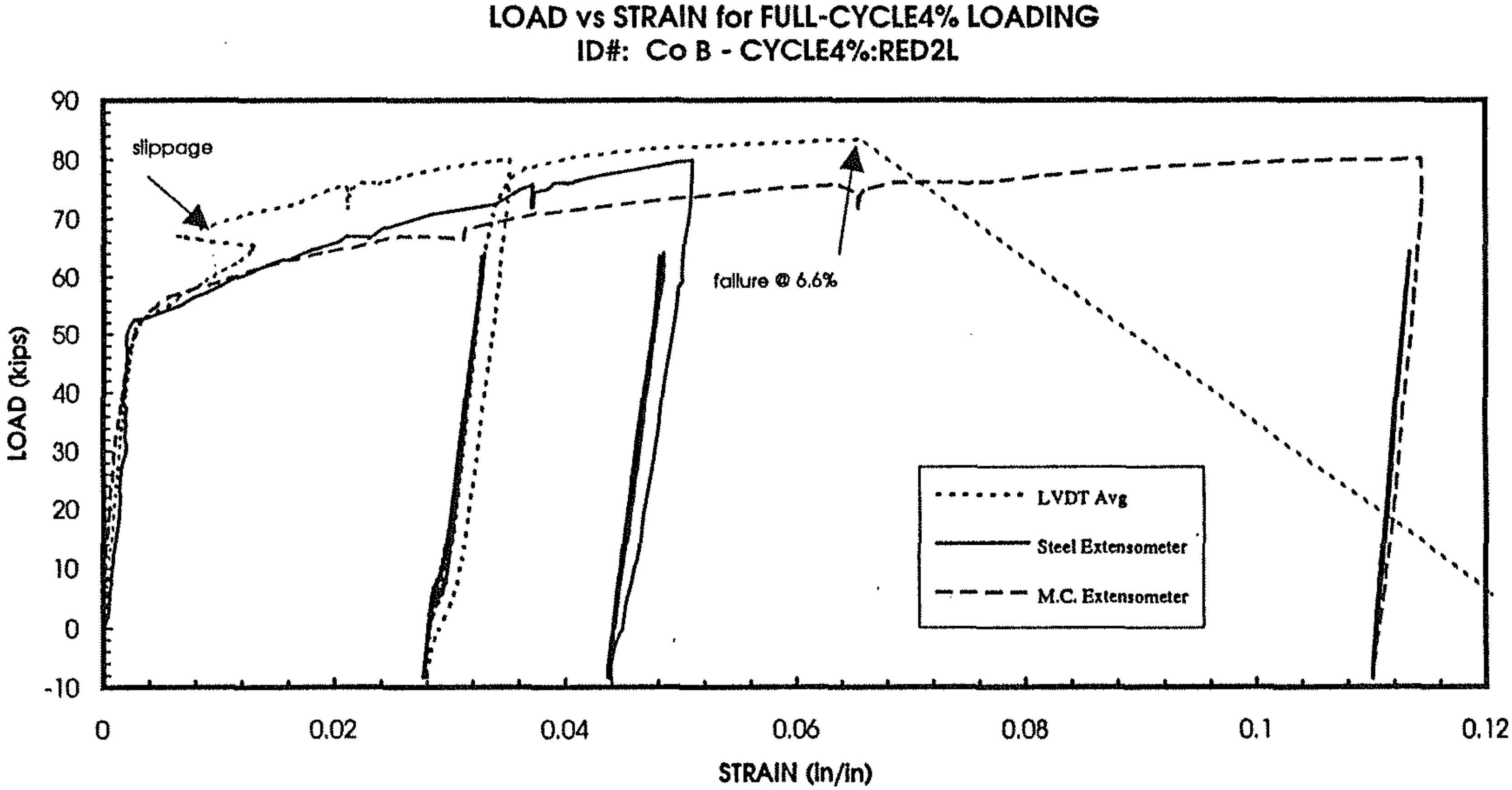

LOAD vs STRAIN for FULL-CYCLE4% LOADING
ID#: Co B - CYCLE4%:RED2L
LOAD (kips)
90
80
70
60
50
40
30
20
10
0
-10
0
0.02
0.04
0.06
0.08
0.1
0.12
STRAIN (in/in)
slippage
failure @ 6.6%
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 13b

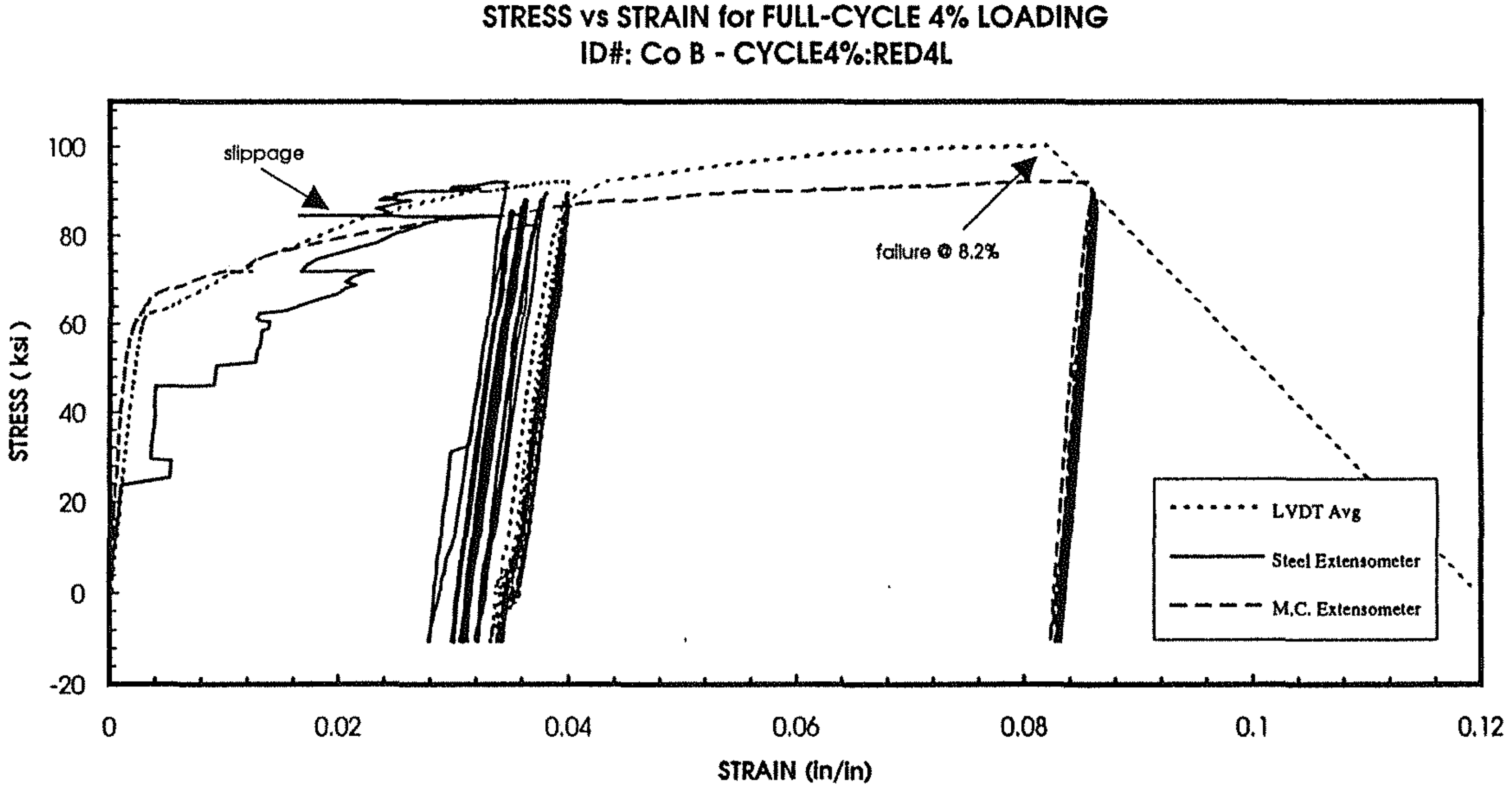

STRESS vs STRAIN for FULL-CYCLE 4% LOADING
ID#: Co B - CYCLE4%:RED4L
slippage
failure @ 8.2%
STRESS (ksi)
100
80
60
40
20
0
-20
0
0.02
0.04
0.06
0.08
0.1
0.12
STRAIN (in/in)
LVDT Avg
Steel Extensometer
M.C. Extensometer

Figure 14a

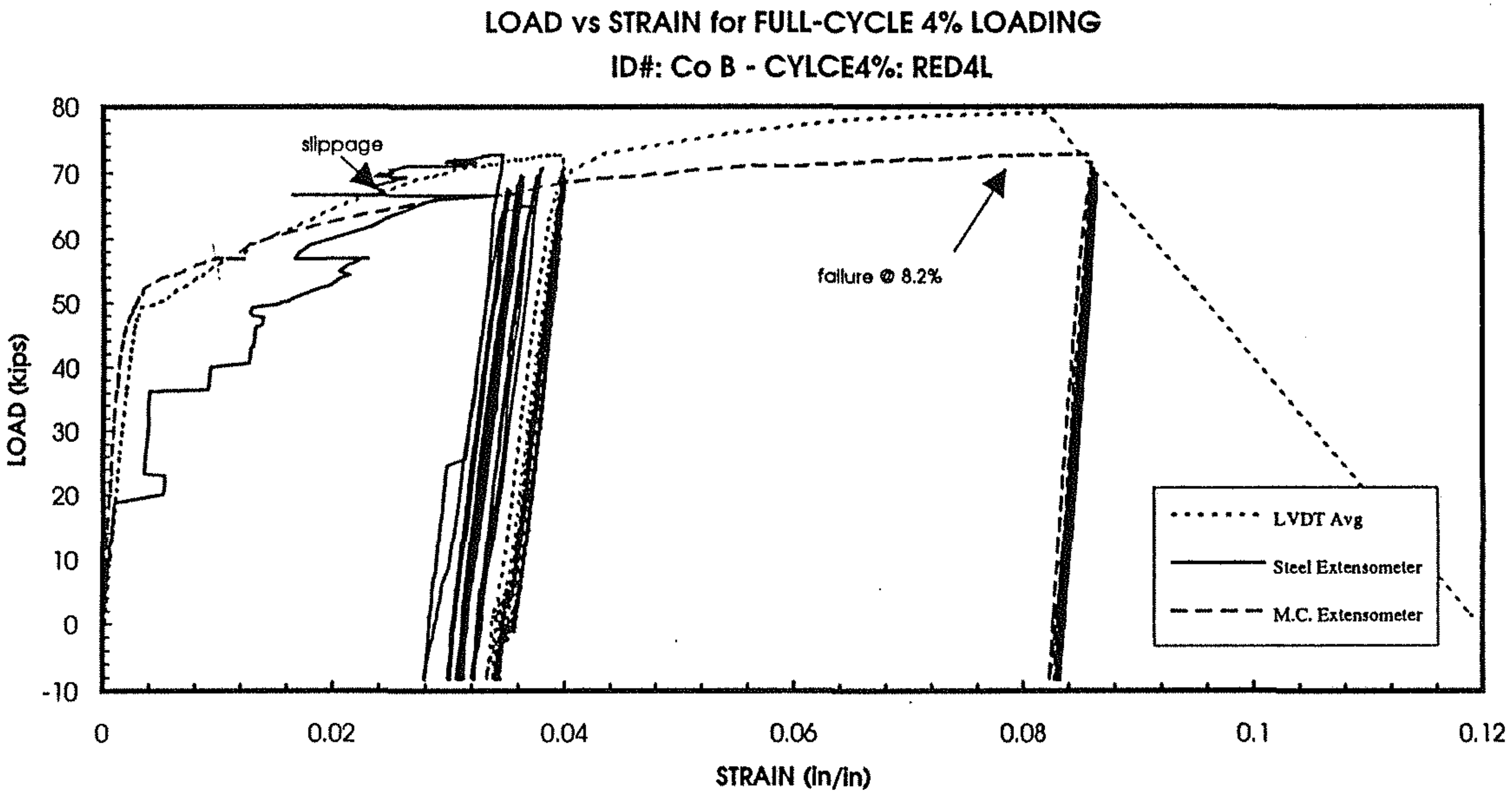

LOAD vs STRAIN for FULL-CYCLE 4% LOADING
ID#: Co B - CYLCE4%: RED4L
slippage
failure @ 8.2%
LVDT Avg
Steel Extensometer
M.C. Extensometer
LOAD (kips)
80
70
60
50
40
30
20
10
0
-10
0
0.02
0.04
0.06
0.08
0.1
0.12
STRAIN (in/in)

Figure 14b

8B-2Y Bargrip Swagged (Yellow)

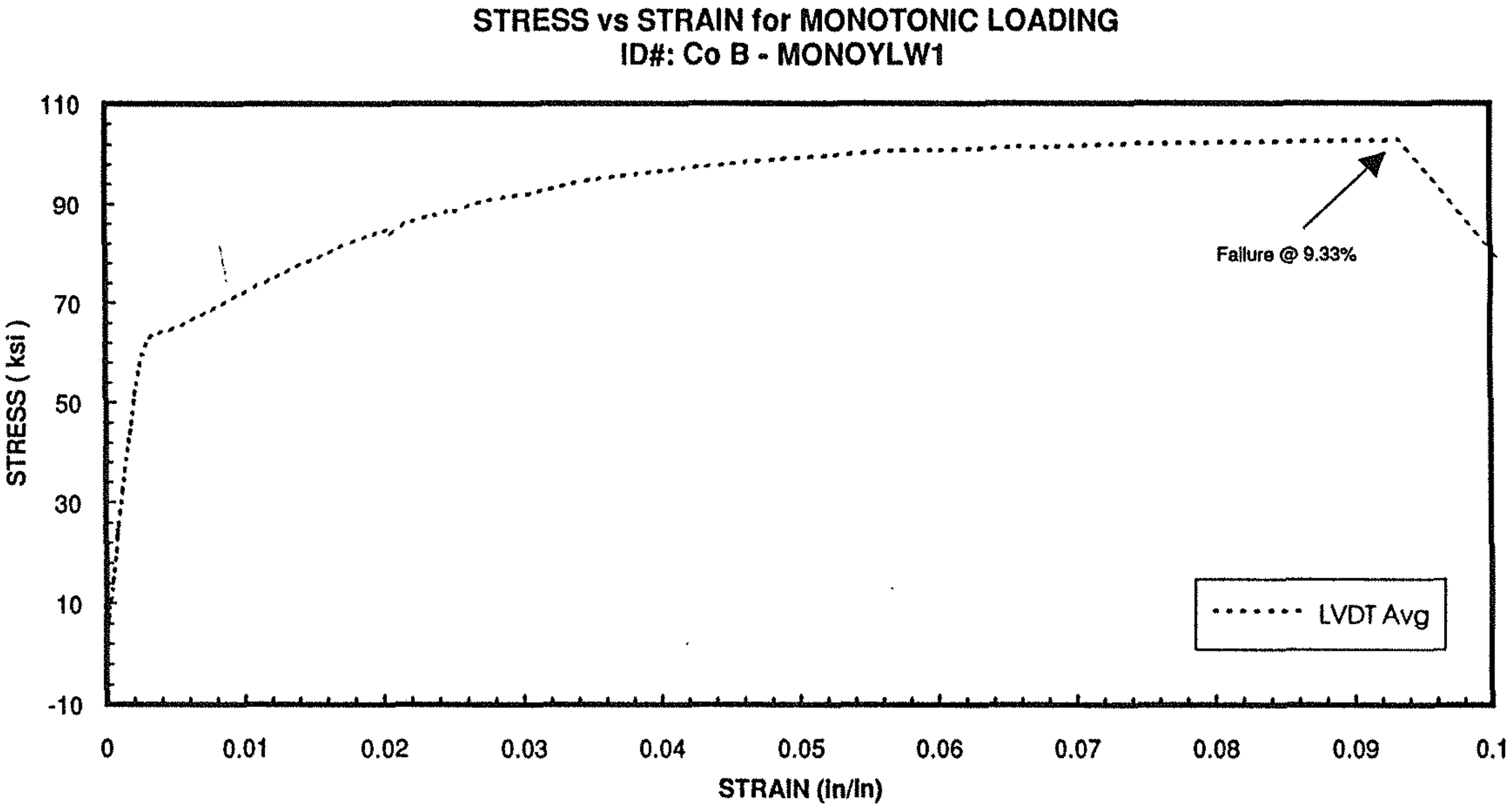

STRESS vs STRAIN for MONOTONIC LOADING
ID#: Co B - MONOYLW1
110
90
70
50
30
10
-10
STRESS (ksi)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
STRAIN (In/In)
Failure @ 9.33%
LVDT Avg

Figure 15a

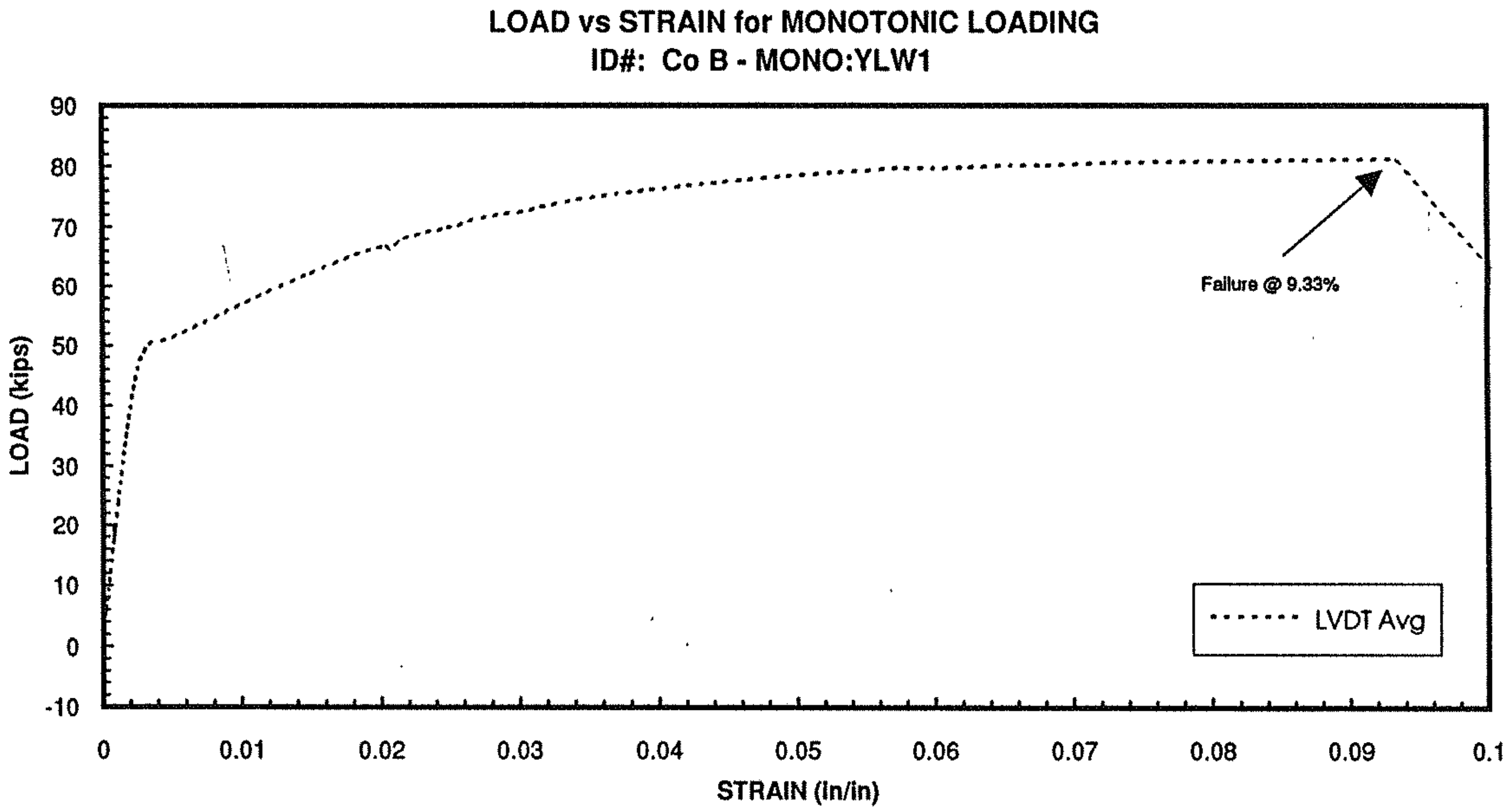

LOAD vs STRAIN for MONOTONIC LOADING
ID#: Co B - MONO:YLW1
LOAD (kips)
90
80
70
60
50
40
30
20
10
0
-10
STRAIN (in/in)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Failure @ 9.33%
LVDT Avg

Figure 15b

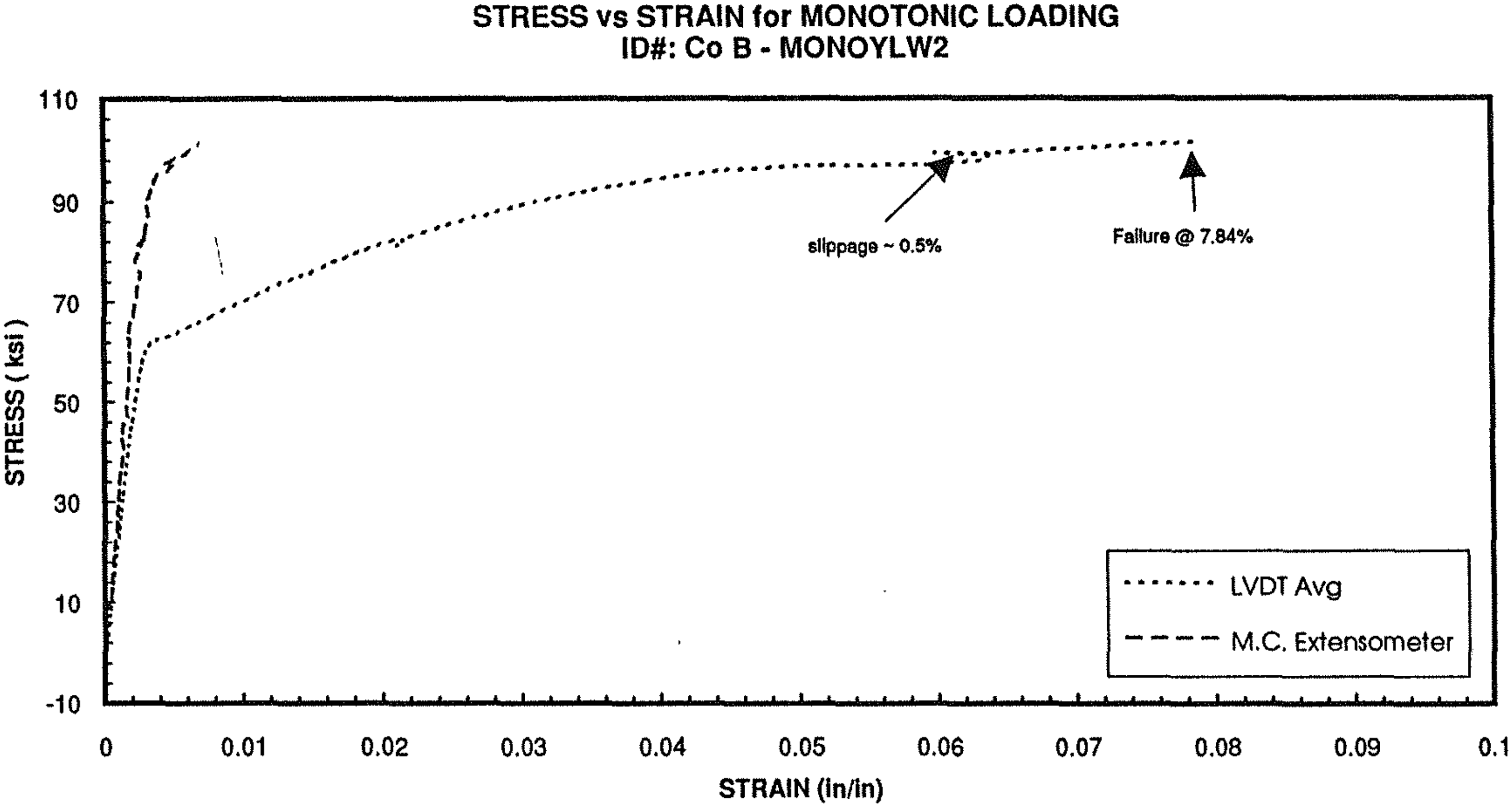
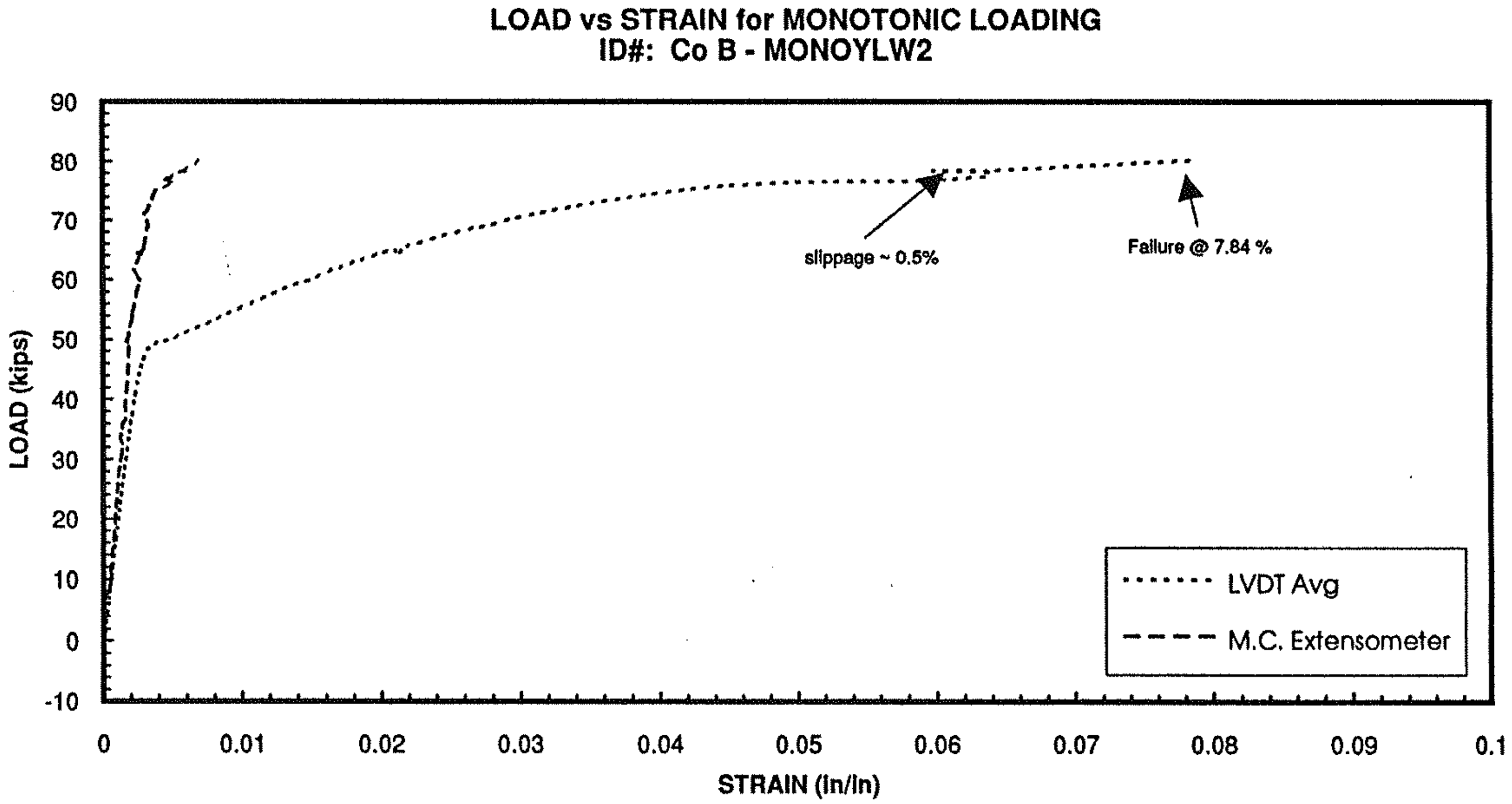

STRESS vs STRAIN for MONOTONIC LOADING
ID#: Co B - MONOYLW2
STRESS (ksi)
110
90
70
50
30
10
-10
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
STRAIN (in/in)
slippage ~ 0.5%
Failure @ 7.84%
LVDT Avg
M.C. Extensometer

Figure 16a



LOAD vs STRAIN for MONOTONIC LOADING
ID#: Co B - MONOYLW2

Figure 16b

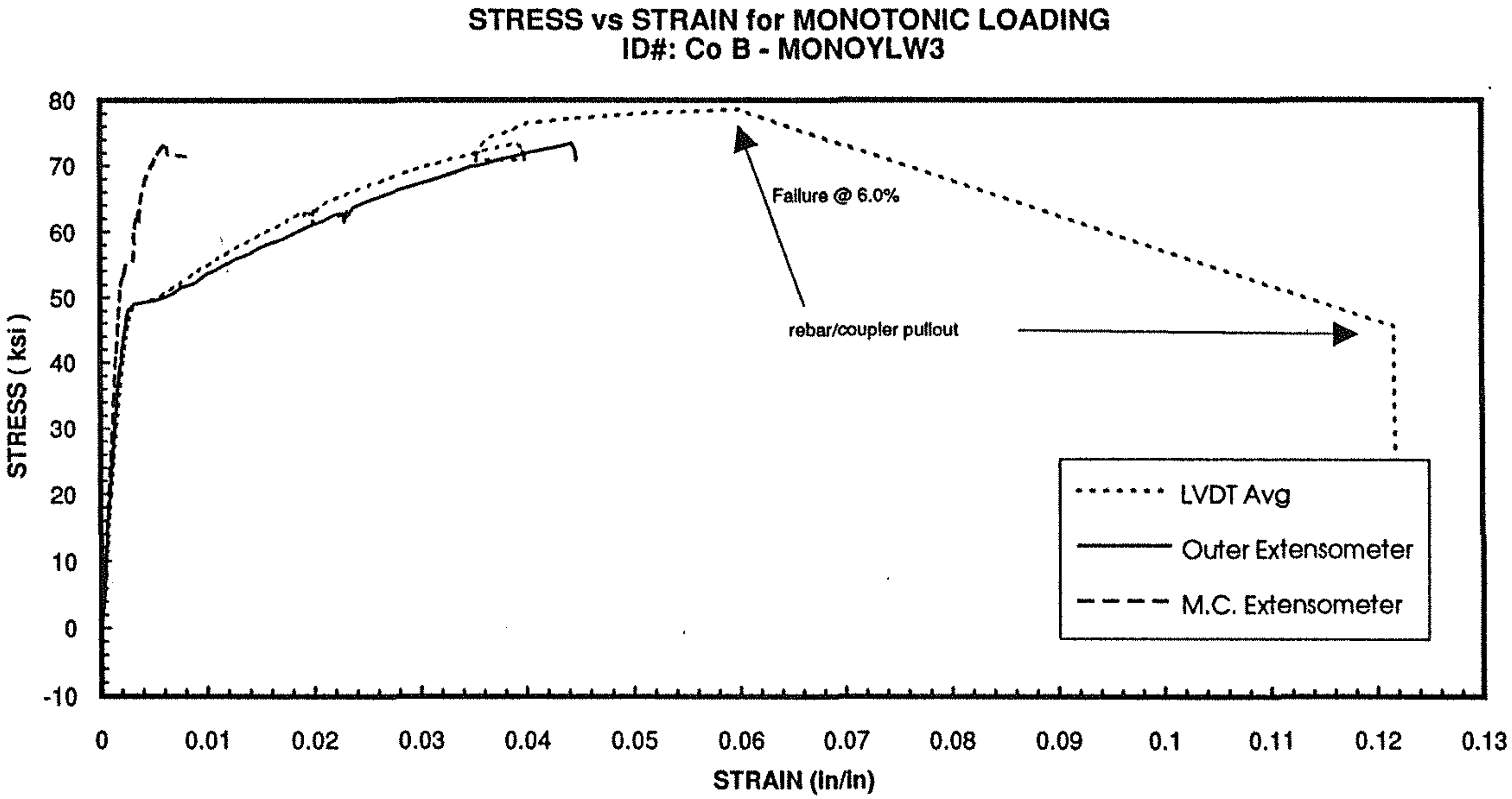
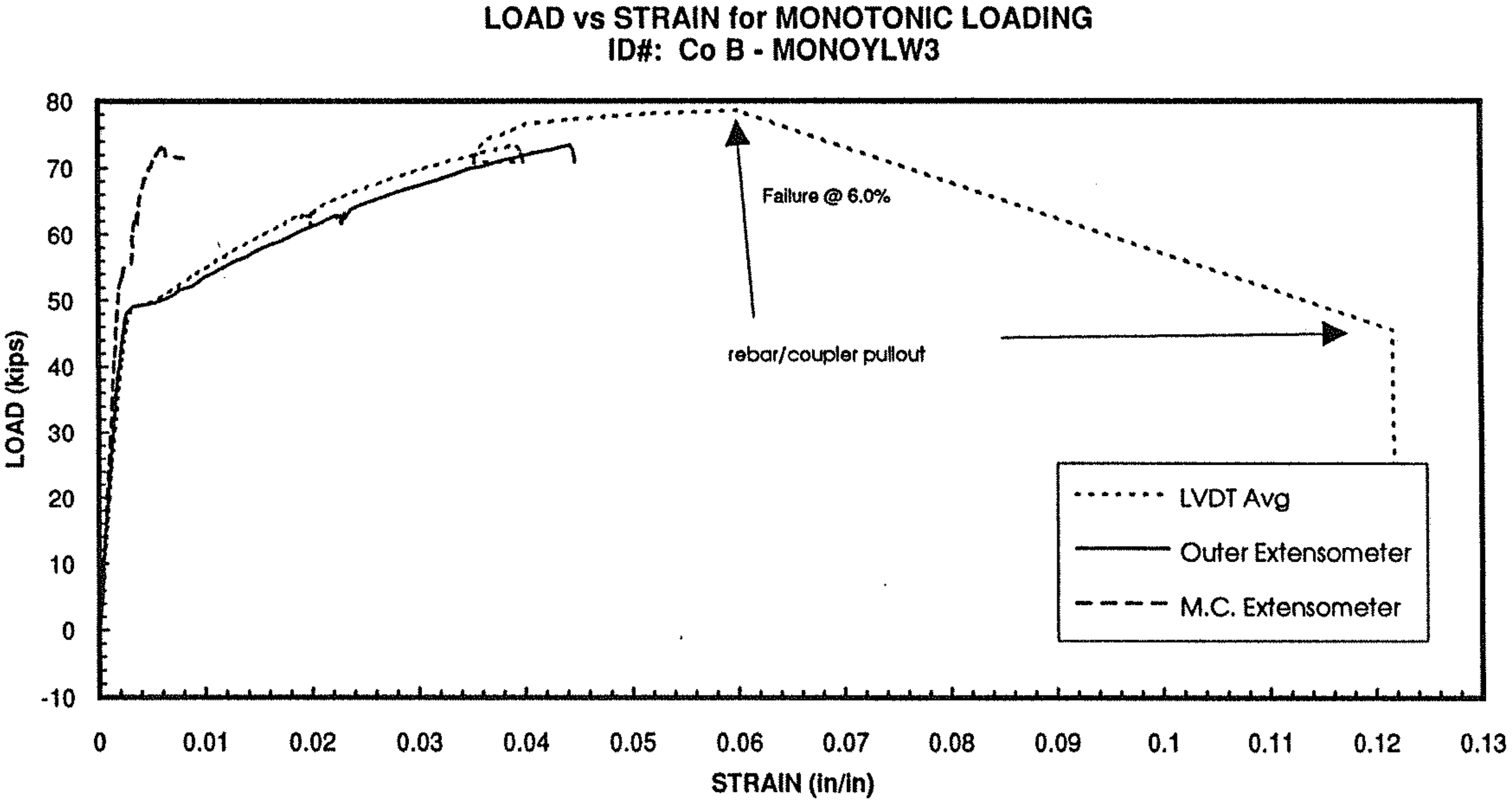

STRESS vs STRAIN for MONOTONIC LOADING
ID#: Co B - MONOYLW3
STRESS (ksi)
80
70
60
50
40
30
20
10
0
-10
STRAIN (In/In)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.11
0.12
0.13
Failure @ 6.0%
rebar/coupler pullout
LVDT Avg
Outer Extensometer
M.C. Extensometer

Figure 17a



LOAD vs STRAIN for MONOTONIC LOADING
ID#: Co B - MONOYLW3
LOAD (kips)
80
70
60
50
40
30
20
10
0
-10
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.11
0.12
0.13
STRAIN (in/in)
Failure @ 6.0%
rebar/coupler pullout
LVDT Avg
Outer Extensometer
M.C. Extensometer

Figure 17b

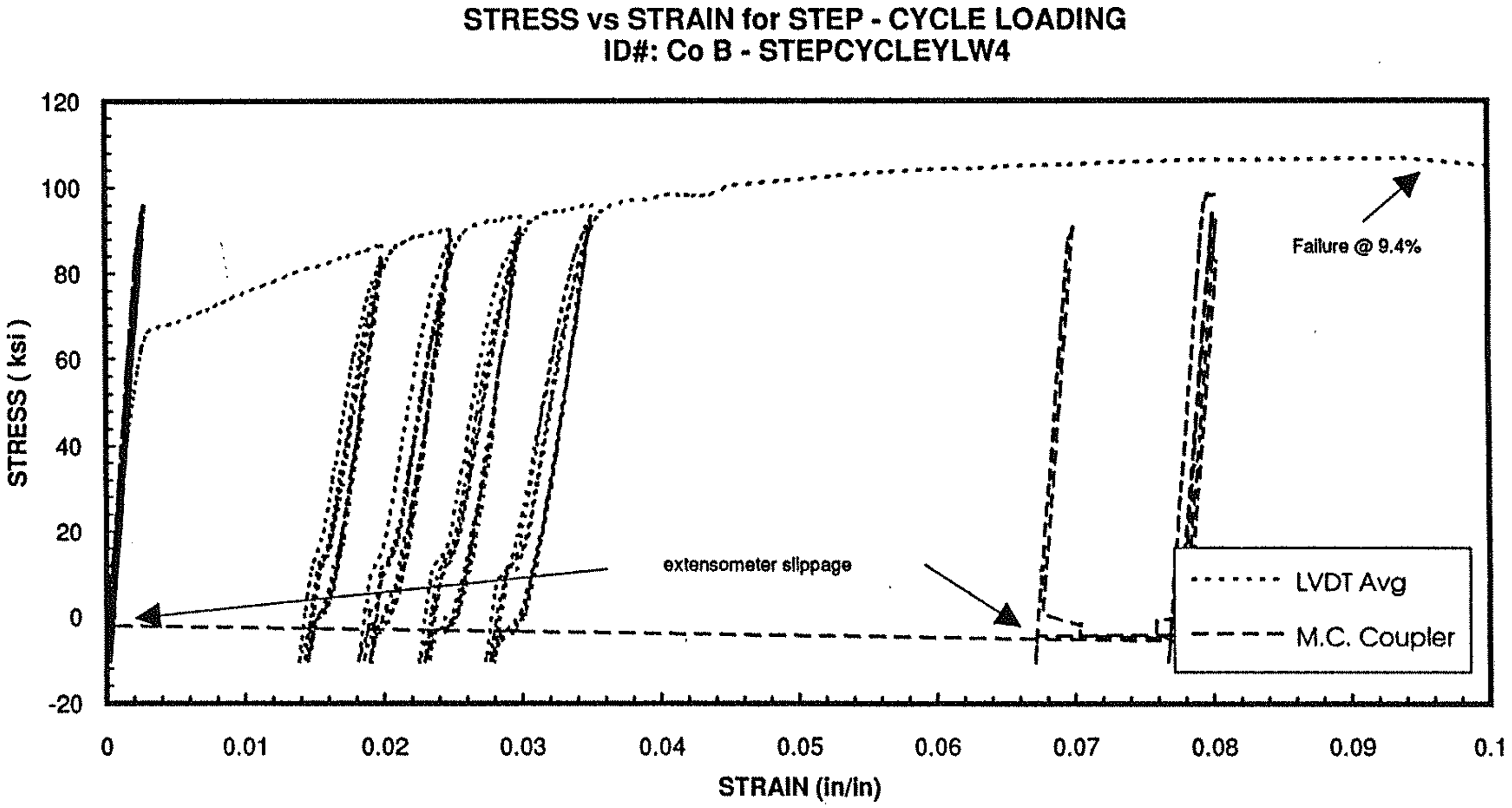

STRESS vs STRAIN for STEP - CYCLE LOADING
ID#: Co B - STEPCYCLEYLW4
120
100
80
60
40
20
0
-20
STRESS (ksi)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
STRAIN (in/in)
Failure @ 9.4%
extensometer slippage
LVDT Avg
M.C. Coupler

Figure18a

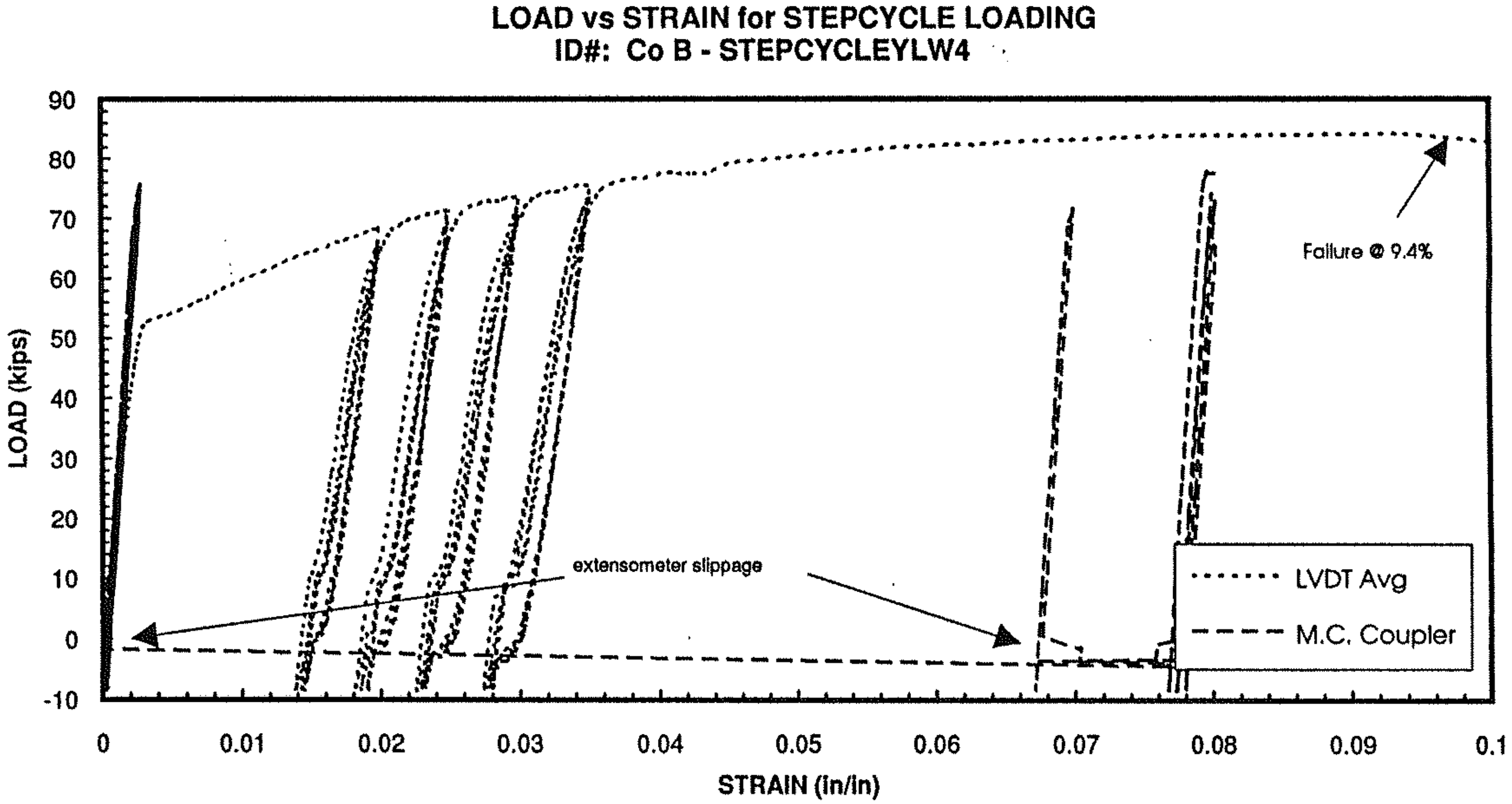

LOAD vs STRAIN for STEPCYCLE LOADING
ID#: Co B - STEPCYCLEYLW4
LOAD (kips)
90
80
70
60
50
40
30
20
10
0
-10
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
STRAIN (in/in)
Failure @ 9.4%
extensometer slippage
LVDT Avg
M.C. Coupler

Figure 18b

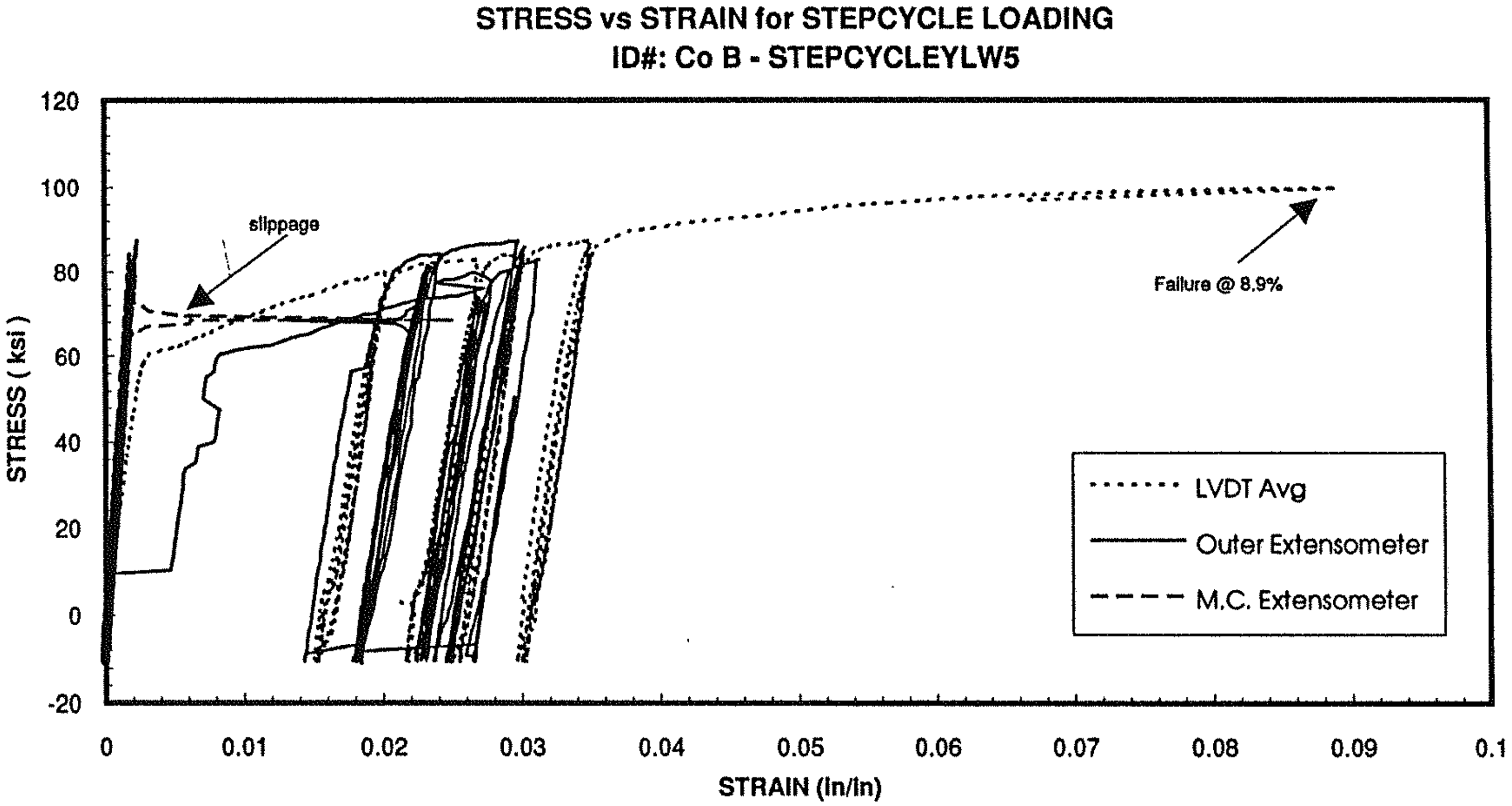

STRESS vs STRAIN for STEPCYCLE LOADING
ID#: Co B - STEPCYCLEYLW5
STRESS (ksi)
120
100
80
60
40
20
0
-20
STRAIN (in/in)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
slippage
Failure @ 8.9%
LVDT Avg
Outer Extensometer
M.C. Extensometer

Figure 19a

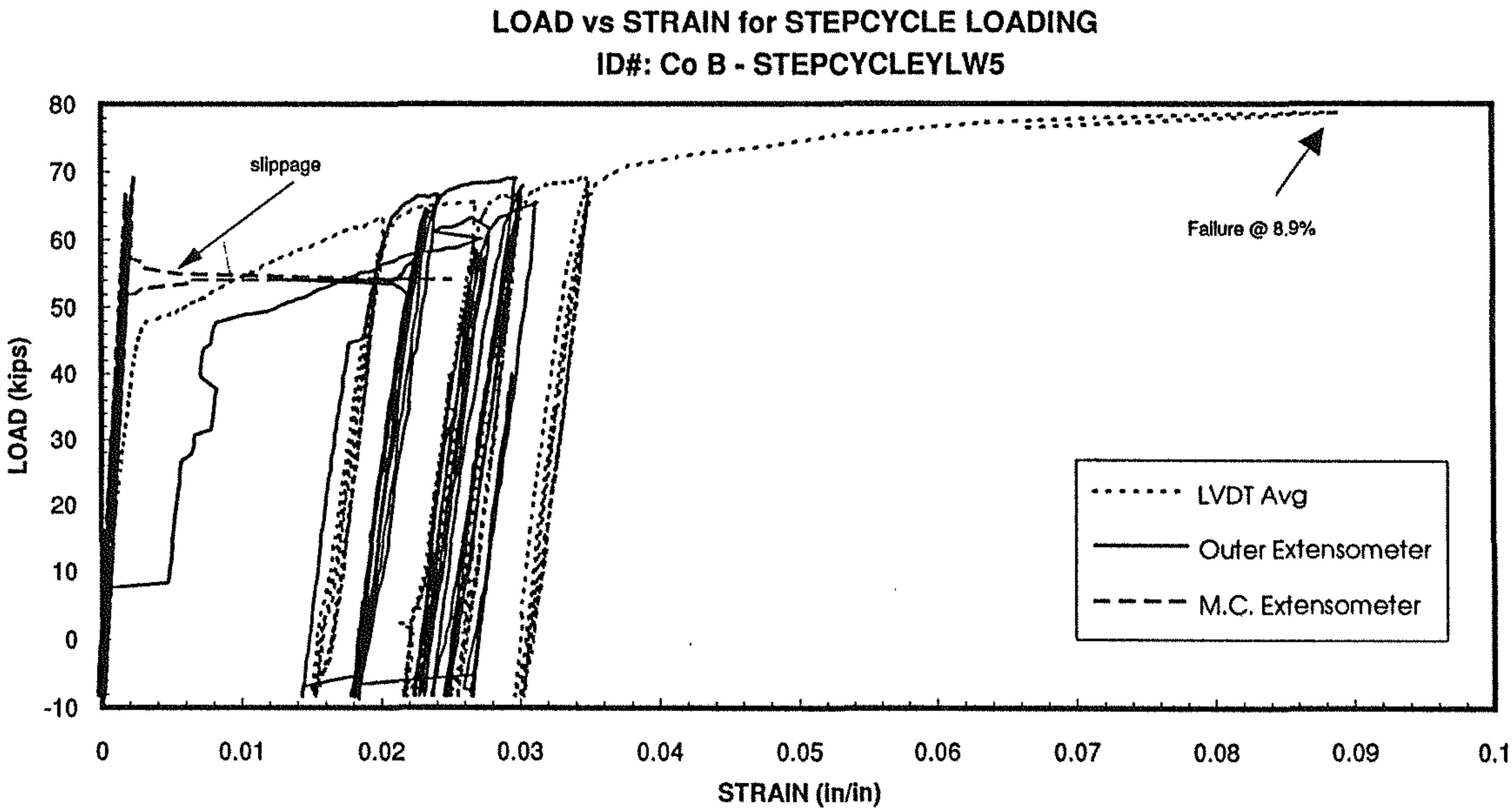

LOAD vs STRAIN for STEPCYCLE LOADING
ID#: Co B - STEPCYCLEYLW5
80
70
60
50
40
30
20
10
0
-10
LOAD (kips)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
STRAIN (in/in)
slippage
Failure @ 8.9%
LVDT Avg
Outer Extensometer
M.C. Extensometer

Figure 19b

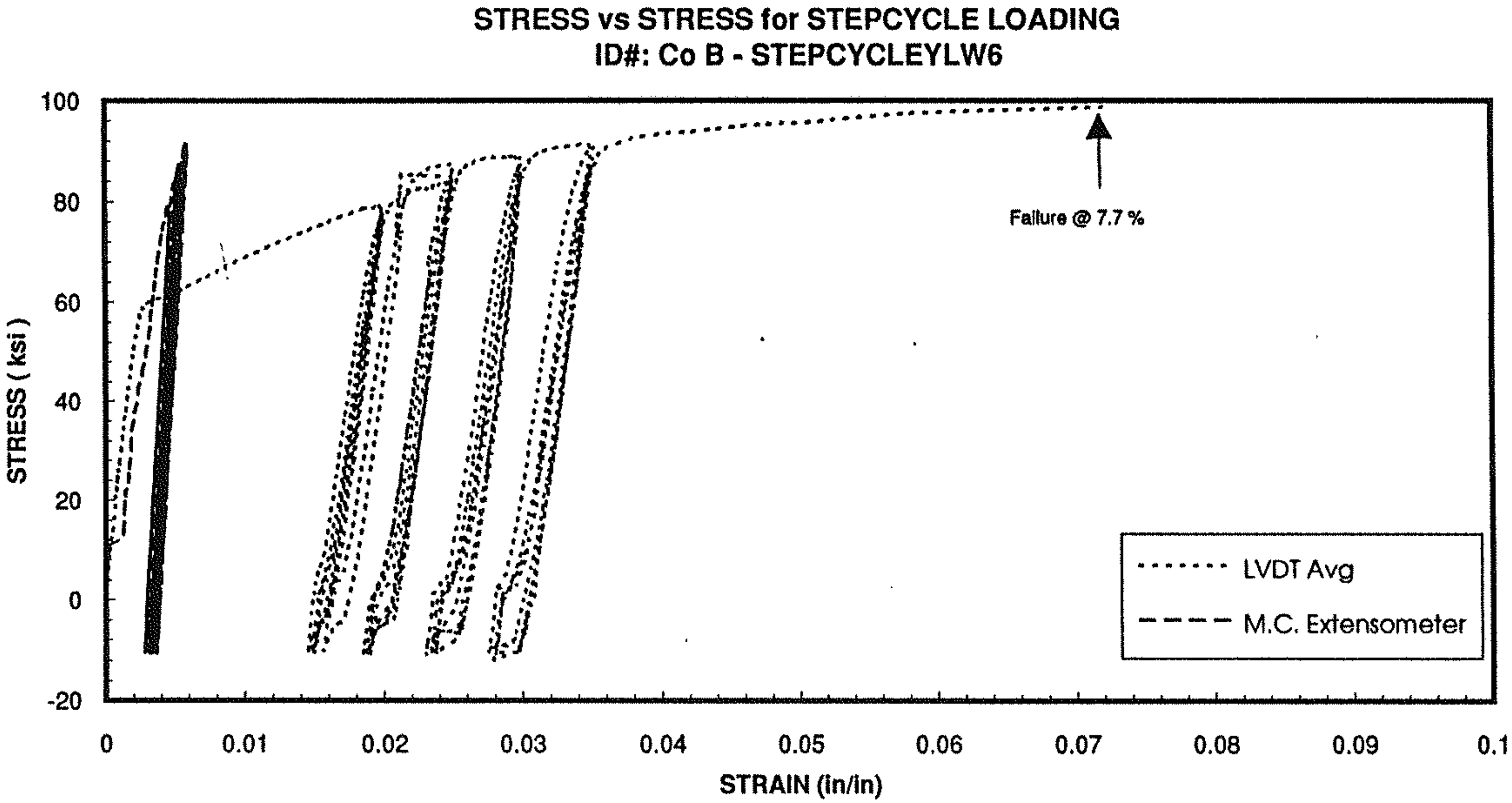

STRESS vs STRESS for STEPCYCLE LOADING
ID#: Co B - STEPCYCLEYLW6
100
80
60
40
20
0
-20
STRESS (ksi)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
STRAIN (in/in)
Failure @ 7.7 %
LVDT Avg
M.C. Extensometer

Figure 20a

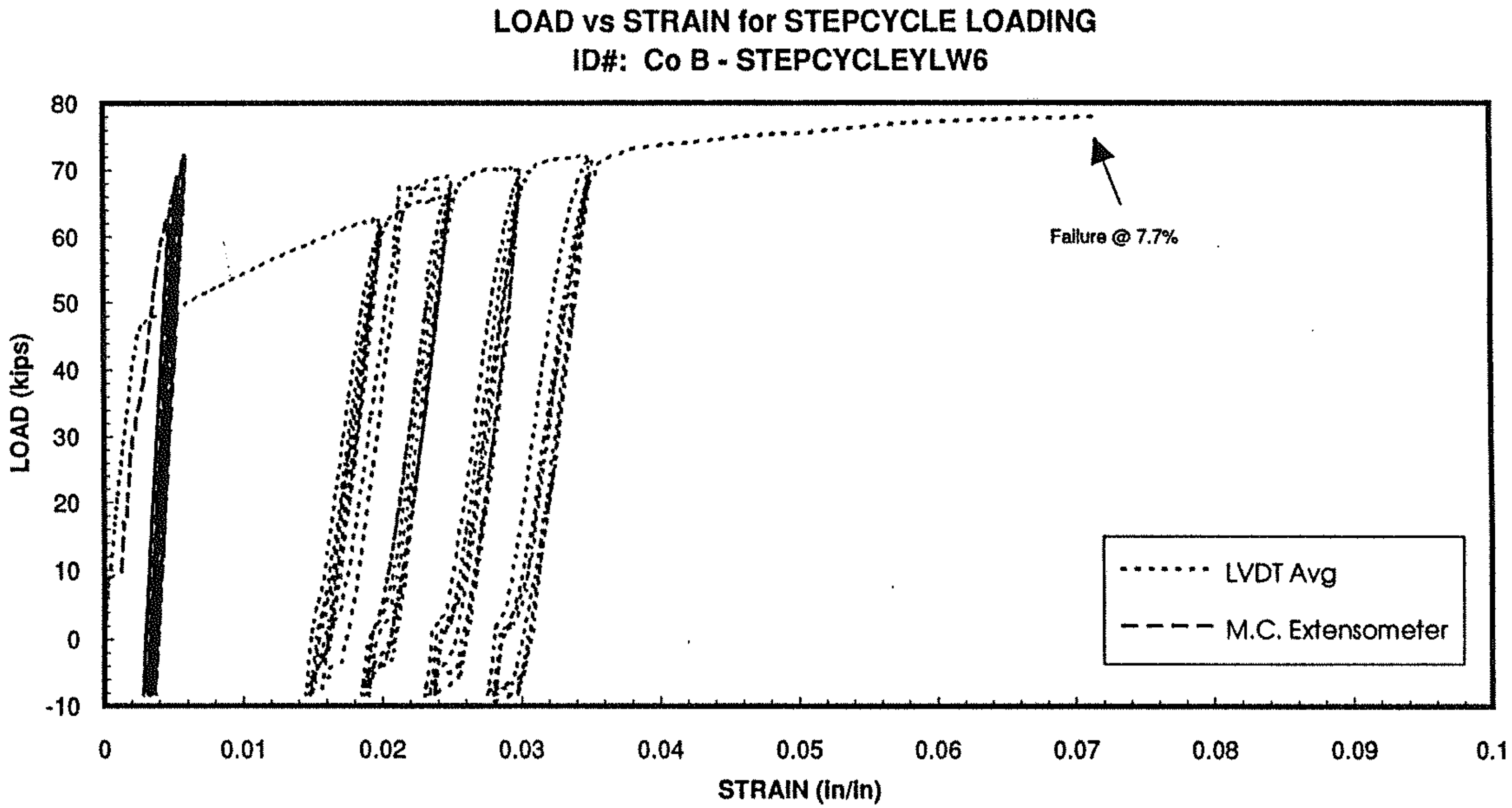

LOAD vs STRAIN for STEPCYCLE LOADING
ID#: Co B - STEPCYCLEYLW6
LOAD (kips)
80
70
60
50
40
30
20
10
0
-10
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
STRAIN (in/in)
Failure @ 7.7%
LVDT Avg
M.C. Extensometer

Figure 20b

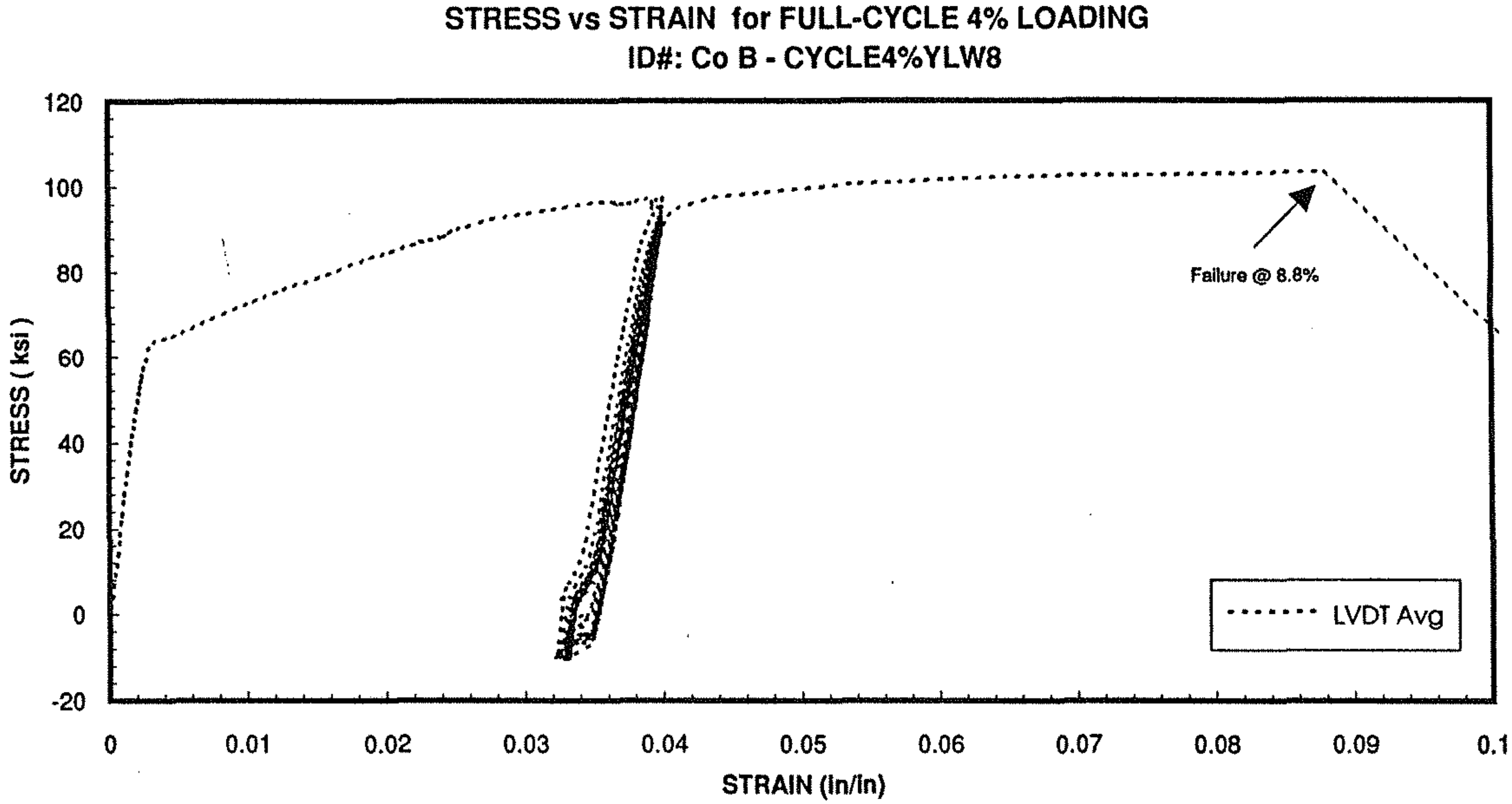

STRESS vs STRAIN for FULL-CYCLE 4% LOADING
ID#: Co B - CYCLE4%YLW8
STRESS (ksi)
120
100
80
60
40
20
0
-20
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
STRAIN (In/In)
Failure @ 8.8%
LVDT Avg

Figure 21a

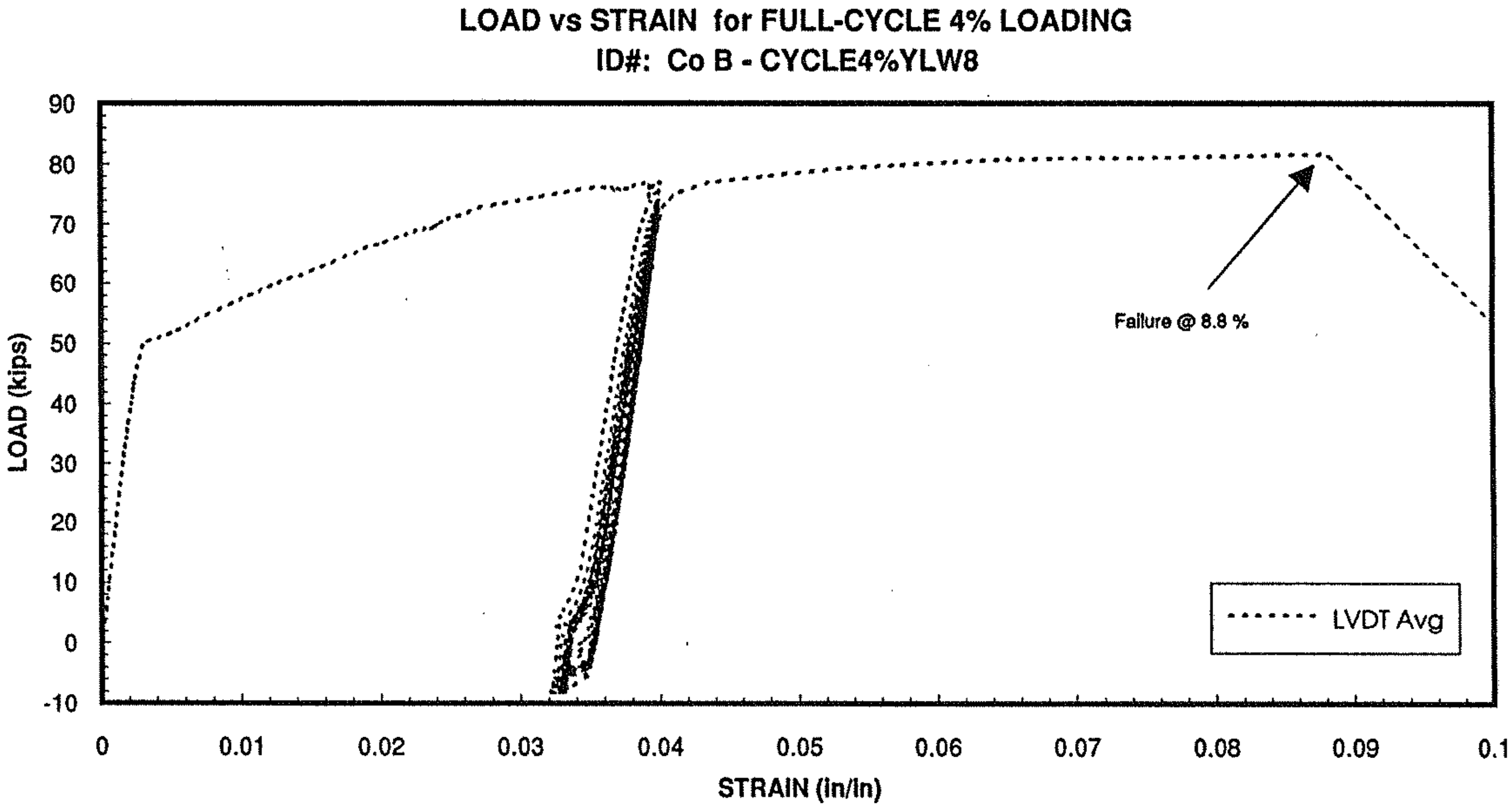

LOAD vs STRAIN for FULL-CYCLE 4% LOADING
ID#: Co B - CYCLE4%YLW8
LOAD (kips)
90
80
70
60
50
40
30
20
10
0
-10
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
STRAIN (In/In)
Failure @ 8.8 %
LVDT Avg

Figure 21b

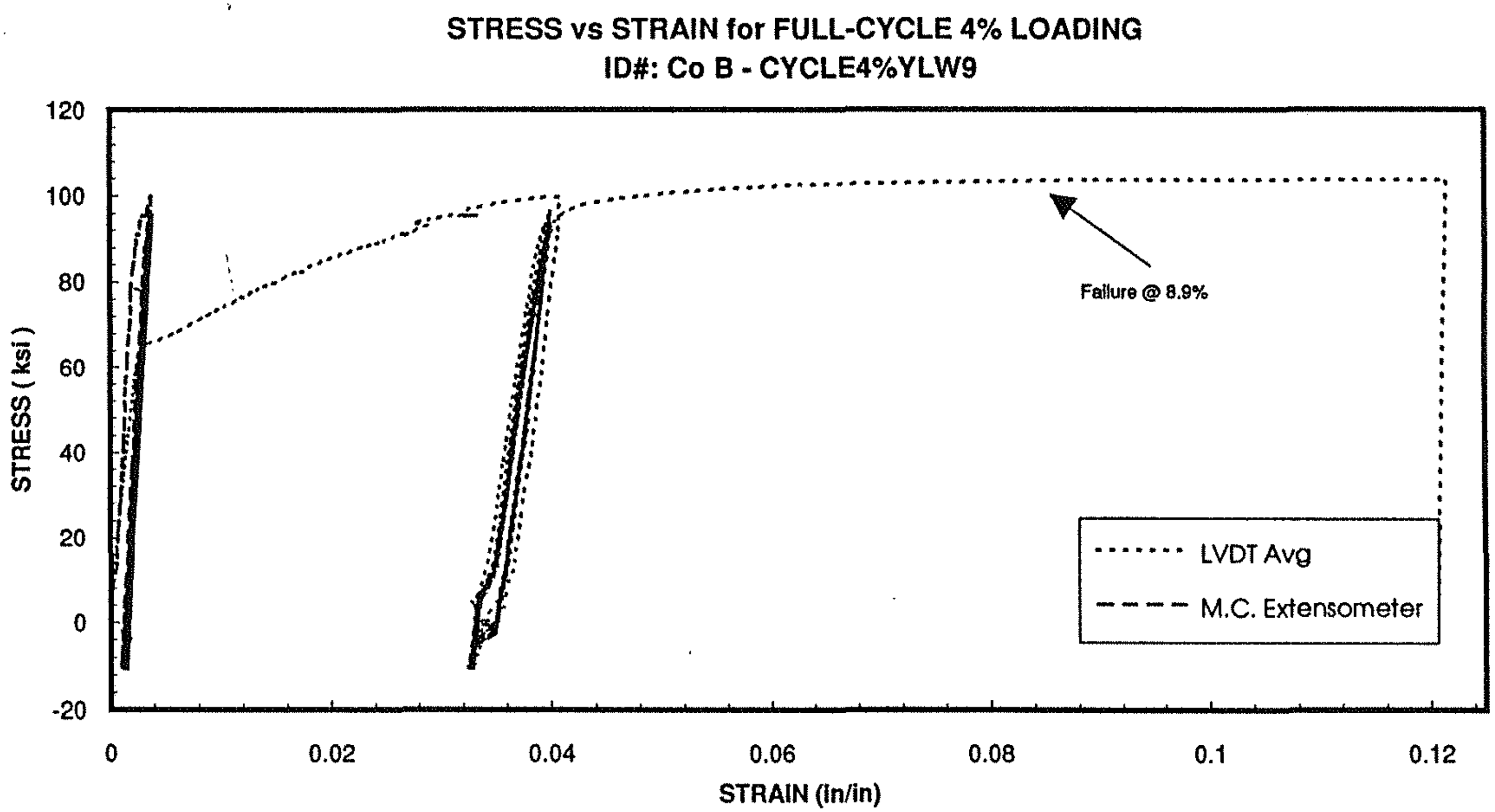

STRESS vs STRAIN for FULL-CYCLE 4% LOADING
ID#: Co B - CYCLE4%YLW9
STRESS (ksi)
120
100
80
60
40
20
0
-20
0
0.02
0.04
0.06
0.08
0.1
0.12
STRAIN (in/in)
Failure @ 8.9%
LVDT Avg
M.C. Extensometer

Figure 22a

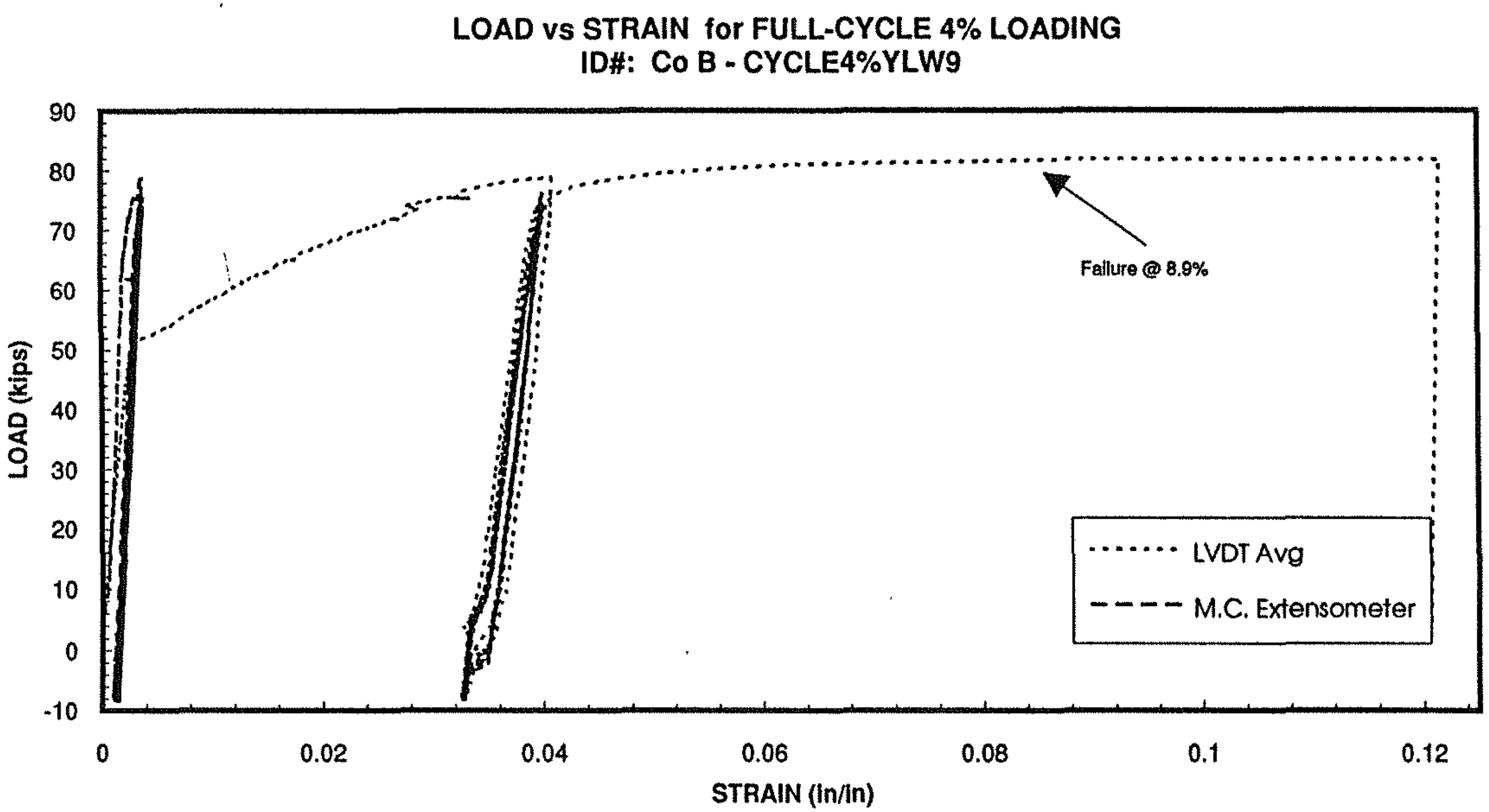

LOAD vs STRAIN for FULL-CYCLE 4% LOADING
ID#: Co B - CYCLE4%YLW9
LOAD (kips)
90
80
70
60
50
40
30
20
10
0
-10
0
0.02
0.04
0.06
0.08
0.1
0.12
STRAIN (in/in)
Failure @ 8.9%
LVDT Avg
M.C. Extensometer

Figure 22b