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Study of Braking Operations Using a Locomotive Simulator

Office of Research
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Washington, DC 20590

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Administration
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The Volpe Center is currently supporting the Federal Railroad Administration in developing revisions to the safety standards for train air brakes. As part of the program, one of the tasks was to evaluate the effects certain operating parameters have on the performance and response of braking operations. A Locomotive Engineer Training Simulator (LETS) was used to perform a series of braking operations with different combinations of operating parameters. A log which documented the results was generated for each train simulation. After the simulations were completed, results from the log were reorganized and translated into plots for analysis. This report summarizes the results from the analysis.

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Preface

The Volpe National Transportion Systems Center is currently supporting the Federal Railroad Administration (FRA), Office of Research and Development in developing revisions to the safety standards for train air brakes. As part of the program, the Volpe Center conducted engineering studies related to the safety of train braking systems. These studies included evaluating the types of effects a number of operating parameters have on the performance and response of the braking operations.

A Locomotive Engineer Training Simulator (LETS) from the Springfield Terminal Railway was used to perform this task. Train simulations for different combinations of operating parameters were performed on the LETS. These operating parameters included: the engineers themselves, train consist, braking operations, percentage of brake outages, distribution of brake outages, and terrain. This report summarizes results obtained from train simulations performed on the Springfield Terminal Railway locomotive simulator.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2 = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2 = 0.09 square meter (m_2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

$[(x-32)(5/9)]\ ^{o}F = y\ ^{o}C$

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yeards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliters (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

$[(9/5)\ y + 32]\ ^{o}C = x\ ^{o}F$

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES: 0 1 2 3 4 5 6 7 8 9 10

CENTIMETERS: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 25.40

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

^{o}F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
^{o}C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

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Executive Summary

This technical report summarizes results obtained from train simulations performed on a Locomotive Engineer Training Simulator (LETS). Simulations for different combinations of operating parameters were performed by three qualified supervisory engineers. The purpose of the task was to evaluate the effects different operating parameters have on the performance and response of braking operations.

Train simulations were performed over a period of three days with one engineer performing each day. All engineers performed the same sequence of train simulations. The simulations selected were varied by six factors: the engineers themselves, train consist, braking operations, percentage of brake outages, distribution of brake outages, and terrain. The two consists used were a 100-car unit coal train and a 100-car trailer train. Every car in the coal train consist was fully loaded and the trailer train was composed of full-loads, half-loads and empties.

The engineers performed the braking operations without significantly exceeding the maximum allowable safety limits during all train simulations. Buff forces were very small during power braking operations for both consists, but became significant when dynamic braking was applied. Dynamic braking operations with 20% brake outage were on the edge of handling difficulties. The simulations indicated that performing braking operations with only the dynamic brake, without any aid of the power brake, would be expected to be accompanied by a significant increase in buff forces.

Introduction

The Volpe National Transportation Systems Center is currently supporting the Federal Railroad Administration (FRA) in developing revisions to the safety standards for train air brakes. As part of this program, a task was developed to evaluate the effects certain operating parameters have on the performance and response of braking operations. Train simulations for different combinations of operating parameters were performed on a Locomotive Engineer Training Simulator (LETS) provided by the Springfield Terminal Railway Company.

The LETS is an FRA Type II simulator. It is generally used to test an engineer's operational performance in accordance with the Federal Railroad Administration Locomotive Engineer Qualification and Certification Regulations. A log documenting results was generated for each train simulation. To evaluate train handling difficulties, four operating parameters were considered: type of consist, type of braking operation, percentage of air brake outages, and distribution of air brake outages. After the simulations were completed, results from the log were reorganized and translated into plots for analysis. This technical report summarizes the results from the analysis.

Train Simulations

The LETS is an expanded version of the Train Dynamics Analyzer (TDA) 4000 developed by FM Industries, Inc. It is installed in a mobile trailer with a computer system with graphic display, laser disk video, digital sound, signal display and a locomotive control panel to provide realistic training which closely resembles the sights and sounds of operating an actual train. The simulations selected were varied by six factors: the engineers themselves, train consist, braking operations, percentage of brake outages, distribution of brake outages, and terrain. Each engineer performed braking operations for the operating conditions listed in Table 1.

Three qualified supervisory engineers from the Springfield Terminal Railway Company performed the train simulations. The simulations were completed within three days. A different engineer performed the same runs each day. Each engineer had a different type and level of train operating experience. All three engineers had experience in operating the trailer train and only engineer B had experience in operating the coal train. While engineer C had experience with operating the LETS, the other two (A and B) had never used LETS. Further, engineers A and B had more years of work experience than engineer C in the field of train operations.

Table 1. Braking Operation Conditions

Consist	Braking Operation	% Brake Outage	Brake Outage Distribution #
Coal Train	power braking	0	n/a
		15	1
		15	2
		20	3
	dynamic braking	0	n/a
		15	1
		15	2
		20	3
Van Train	power braking	0	n/a
		15	1
		15	2
		20	3
	dynamic braking	0	n/a
		15	1
		15	2
		20	3

Prior to performing each train simulation, each engineer was given information on the type of consist, number and type of locomotives, load distribution, type of braking operation, and percentage and distribution of brake outage.

To determine the effect different consists have on the braking operations, two consists were used for the train simulation. The two consists were a 100-car unit coal train and a 100-car trailer train (van train, 89-foot flat cars with various loadings). The coal train was heavier, with every car in the consist fully loaded. The van train was lighter, with loads, half-loads and empties distributed as shown in Table 2. This arrangement was chosen for the specific purpose of making the consist prone to run-in during braking. The trailing tonnage was 12,000 for the coal train and 6,000 for the van train.

The braking performance depended greatly on the type of braking operation. To determine the effects a type of braking operation has on performance, both power and dynamic braking operations were performed with both consists. Both types of braking were conducted in accordance with the practices established by the Springfield Terminal Railway Company for operations on its territory.

Table 2. Load Distributions for the 100-car Trailer Train[1]

Car Number	Loading	Net Weight (tons)
1 - 10	empty	450
11 - 35	half load	1500
36 - 45	full load	750
46 - 60	empty	675
61 - 85	half load	1500
86 - 100	full load	1125

Power braking is a method for handling long, heavy trains on undulating grades when dynamic braking is not available. Typically, the throttle is reduced to notch 3 or 4 after the train has started to crest the hill, and a partial service reduction of brake pipe pressure is worked in to balance the grade at or slightly below posted speed. Train speed is then maintained by reducing or increasing the throttle on steeper or flatter grade segments, respectively. Power braking is not fuel-efficient and may require operation at less than full posted track speed on long downgrades in order to avoid car wheel overheating. However, power braking keeps the train in draft, avoiding severe run-ins, and air management on a long downgrade is routine.

Conversely, dynamic braking is fuel-efficient and imposes much less heating on the car wheels. However, proper air management may be somewhat more difficult, and train handling is critical during the setup. Typically, the throttle is reduced in steps to idle as the train crests the hill. Some air braking may be required, depending on the combination of grade, trailing tons, and number of units with operating dynamic brakes. The engineer must judge and apply a minimum-to-partial service reduction, depending on these factors,

[1]Car 94 in the van train consist with 15% brake outage and brake outage distribution #2 was empty and not fully loaded. Car 10 in the van train consist with 20% brake outage was half loaded and not empty.

which will allow the train to be balanced on the grade at or somewhat below posted speed after the dynamic brakes have been brought into action at notch 4 or 5. Train speed is then maintained by increasing or decreasing the dynamic brake application on steeper or flatter grade segments, respectively. Properly graduated initial application of dynamic brakes is essential to avoid severe run-in.

Percentage and distribution of brake outages may also influence the performance of a braking operation. Thus, for each type of braking operation, train simulations were performed with all brakes working and with three different outage conditions as shown in Table 1. The distributions of the two 15% and one 20% brake outage are shown in Table 3. The outages were intentionally concentrated toward the rear end in all cases, subject to limits imposed by the present safety standards[2], in order to maximize run-in propensity. An air brake leakage rate between 1.5 to 1.8 psi/minute was assigned for all train simulations. Table 4 summarizes the type and number of locomotives for each combination of consist and brake outage.

Two segments of track from the Delaware & Hudson Railway were chosen for performance of the train simulations. Most of the simulations were performed between mile posts 532 and 523, with the highest elevation located at MP 527. The track chart for this segment is shown in Figure 2. Braking operations performed on the steep downgrade from MP 527 to MP 523 were expected to have different effects than similar operations performed on level terrain. To evaluate the difference, engineer A performed power braking with a coal train and no brake outage on an undulating segment with almost level average grade (MP 544 to MP 536 in Figure 3).

The trailer equipped with the LETS was transported to the Volpe Center on August 23, 1993. Train simulations were performed between August 24 and August 26 with one of the three engineers operating each day. In general, each engineer performed braking operations in the same sequence as listed in Table 1. The engineer operating on August 24 performed the first run (power braking, coal train consist, no brake outage) on a longer segment of track which included the two segments discussed in the previous paragraph. All the simulations were completed by August 26. The trailer departed the Volpe Center on August 27.

[2]No more than three consecutive cars are allowed to have brakes out.

Table 3. Brake Outage Distributions

Brake Outage Distribution #	Car #
1	78,79,80,83,84,85,88,89,90,93,94,95,98,99,100
2	61,62,63,66,67,68,71,72,73,76,77,78,81,82,83
3	69,70,73,74,75,78,79,80,83,84,85,88,89,90,93,94,95,98,99,100

Table 4. Summary of Locomotives in the Train Simulations

Consist	Brake Outage % and Distribution #		# of Locomotives	Type of Locomotives	Locomotive Power (hp)
Coal Train	0	n/a	5	SD40-2/B02	15000
	15	1	5	SD45-2/B00	18000
	15	2	5	SD50/B00	17500
	20	3	5	SD60/B00	18200
Van Train	0	n/a	4	GP38-2/B00	8000
	15	1	4	GP40-2/B02	12000
	15	2	4	SD40-2/B00	12000
	20	3	4	SD45-2/B00	14400

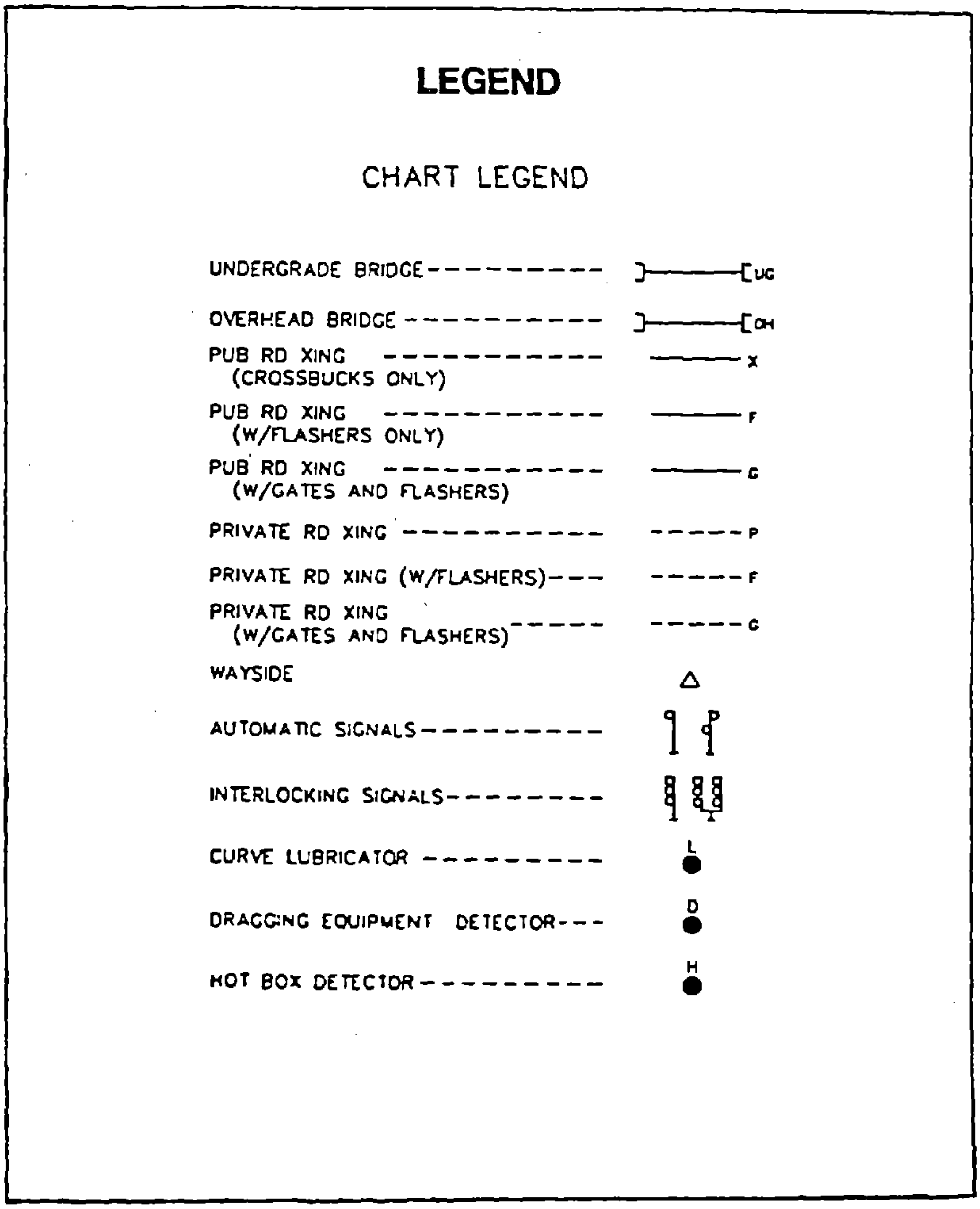

Figure 1. Track Chart Legend

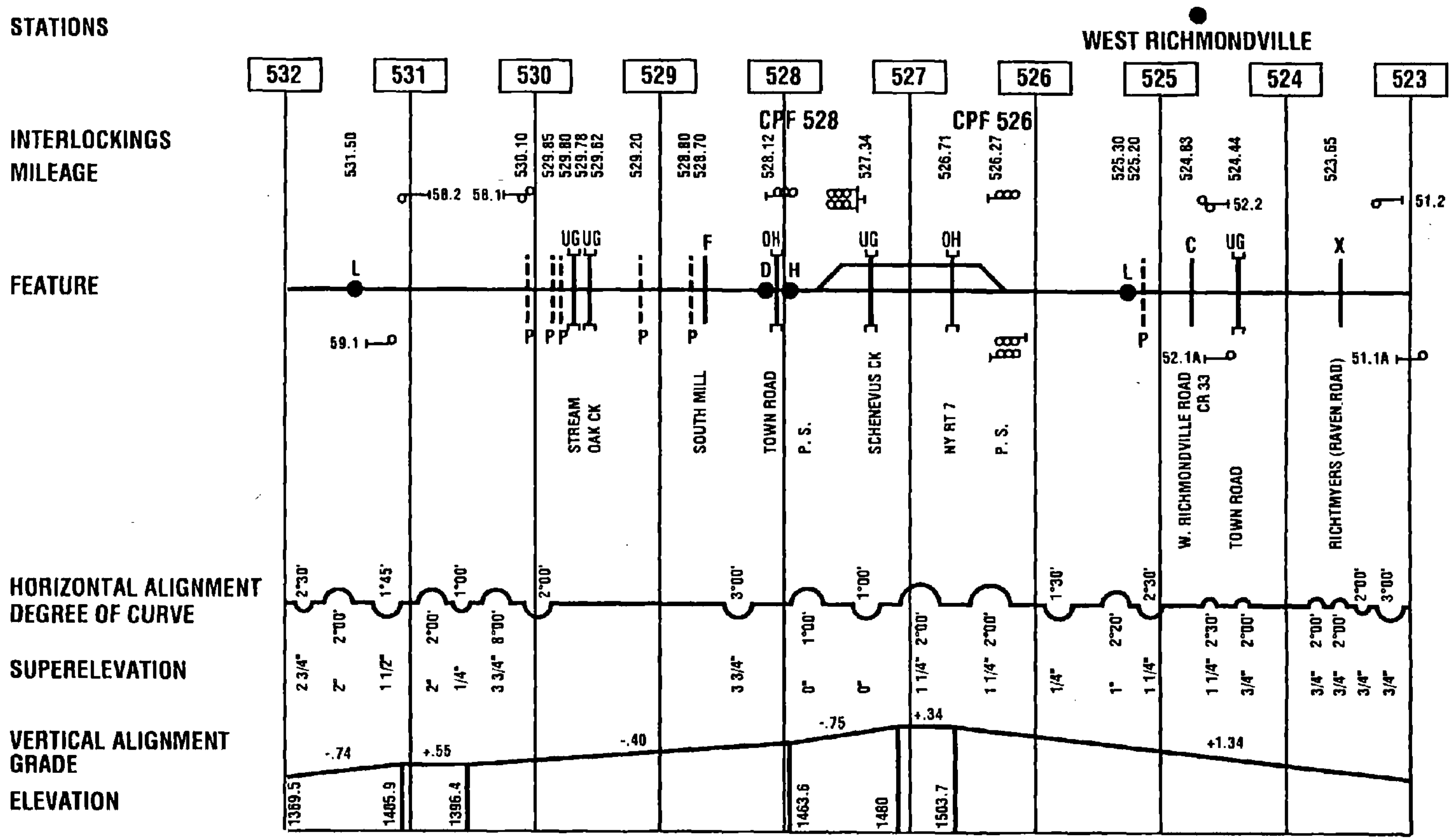

Figure 2. Track Chart between Mile Posts 532 and 523

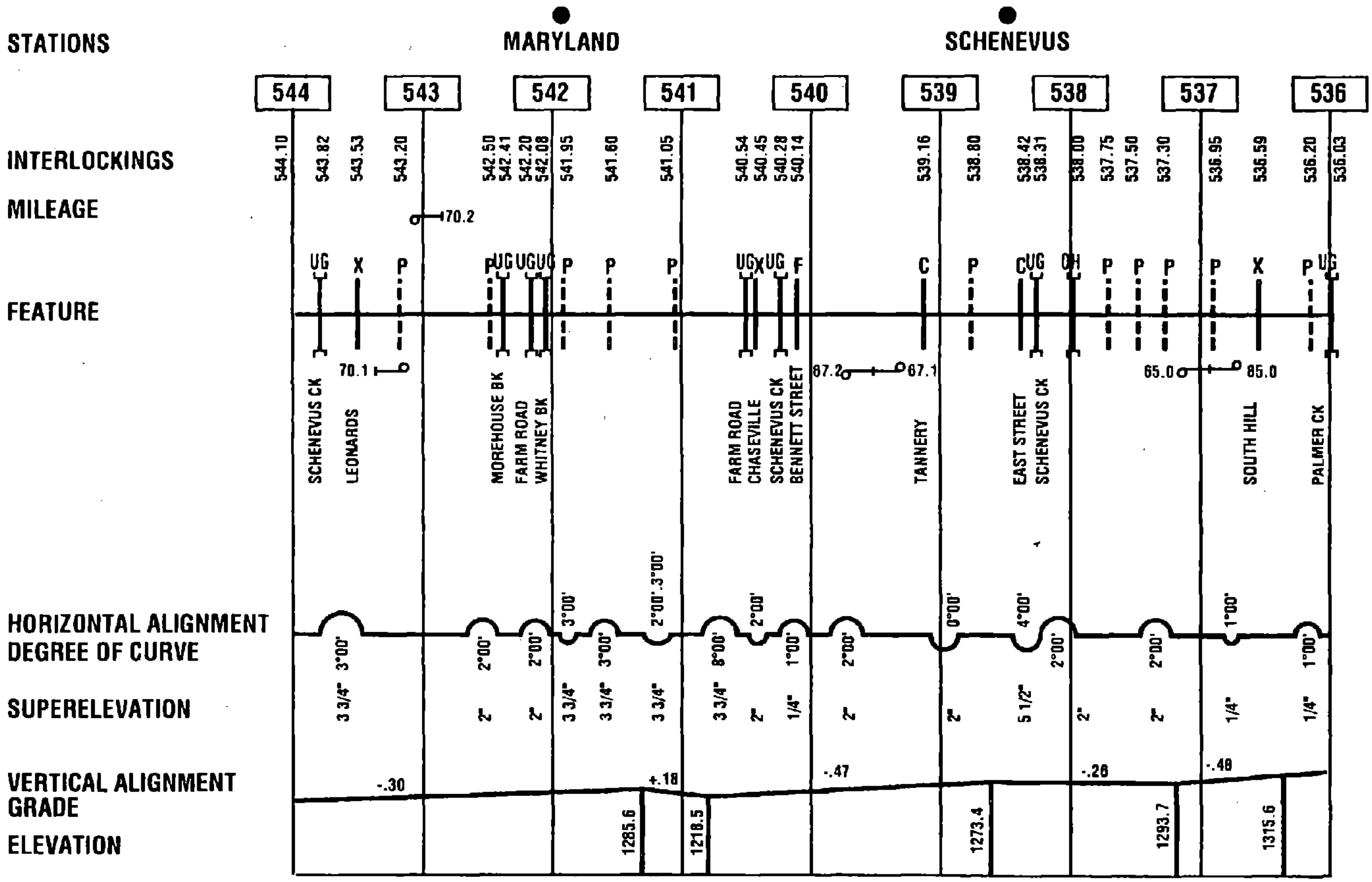

Figure 3. Track Chart between Mile Posts 544 and 536

Results

For each simulation, a comprehensive log which documented the results was generated by the LETS. The log was printed immediately after each simulation and contained information such as speed, maximum draft forces, maximum buff forces, brake pipe pressure, and mile posts for every ten seconds throughout the run. An example of part of the log which was used for data analysis is shown in Table 5. Each set of data was transferred into a data file and plotted on a graph for detailed analysis. These graphs are in Appendices A, B, and C for the three engineers, respectively.

Histograms and line plots were combined to present all the information for each simulation on a single graph. Five parameters were plotted versus mile post: speed, brake pipe pressure, maximum draft forces, maximum buff forces, and maximum (posted) speed. As shown in the appendices, the maximum forces are plotted as histograms with draft forces represented by hollow bars and buff forces by solid bars (Draft forces are positive whereas buff forces are negative). The brake pipe pressure and speed are shown as fine and bold line plots, respectively. The maximum allowable speed is plotted as a bold straight line for reference purposes.

During normal operating conditions, the engineers operated the train without significantly exceeding the maximum allowable speed. The maximum allowable speed was 35 mph when operating the coal train consist and 40 mph when operating the van train consist. As shown in the appendices, during all simulations all three engineers operated the train without significantly exceeding the speed limit. However, during several instances when the engineer was performing the first simulation on the type of consist or with the type of braking operation, he operated the train at more than 10 mph lower than the maximum allowable speed. These situations occurred because the engineer was not familiar with the particular consist or the type of braking operation performed on the consist. Thus, the performance of the engineers generally improved as the number of simulations performed on the consist increased.

All three engineers operated within the allowable limits for draft and buff forces during all train simulations. The maximum allowable draft and buff forces were 300 kips and -250 kips respectively for the coal train and +/- 250 kips for the van train. Although the maximum allowable forces for both draft and buff were the same magnitude, buff forces on a downgrade needed to be monitored closely to prevent significant run-ins which might lead to train derailment. As shown in the appendices, the buff forces were quite small during power braking operations for both consists. Buff forces became significant when dynamic braking was applied, especially for the coal train where some of the buff forces were in the range of 200 kips. For both engineers A and B, there were no significant buff force variations among the coal train simulations

Table 5. Part of a Sample Log Used for Data Analysis

TIME 25Aug93	LOCATION MP.xxx	SPEED Mph	ACCEL Mph/min	L_POS	L_TMC Amps	50_FRC Klbs	MAX_DRAFT Car	MAX_DRAFT Klbs	MAX_BUFF Car	MAX_BUFF Klbs	MAX_S_DFT Car	MAX_S_DFT Klbs	MAX_S_BFF Car	MAX_S_BFF Klbs	MAX_RUN_F Car	MAX_RUN_F Klbs	104_BP Psi	104_CYL Psi	1_BP Psi
00:01.25	531.990	29.8	-11.18	RUN 8	33	3	96	6	18	0	96	6	18	0	15	0	2.0	0.0	0.0
00:11.09	531.909	29.4	3.37	RUN 8	601	64	101	143	6	-20	101	143	8	-2	10	27	89.8	0.0	86.6
00:21.34	531.824	29.9	2.99	RUN 8	599	69	101	146	4	-1	101	146	4	-1	2	37	89.8	0.0	86.6
00:31.18	531.740	30.4	2.77	RUN 8	593	70	101	144	0	0	101	144	0	0	0	0	09.8	0.0	86.6
00:41.04	531.656	30.8	2.45	RUN 8	588	70	101	143	0	0	101	143	0	0	0	0	89.8	0.0	86.6
00:51.30	531.567	31.3	2.38	RUN 8	584	69	101	140	0	0	101	140	0	0	0	0	89.8	0.0	86.6
01:01.14	531.481	31.6	2.24	RUN 8	580	68	101	140	0	0	101	140	0	0	0	0	89.0	0.0	86.6
01:11.39	531.389	32.0	1.98	RUN 8	576	67	101	138	0	0	101	138	0	0	0	0	89.8	0.0	86.6
01:21.23	531.301	32.3	1.77	RUN 8	572	66	101	136	0	0	101	136	0	0	0	0	89.8	0.0	86.6
01:31.10	531.211	32.6	1.65	RUN 8	569	65	101	134	0	0	101	134	0	0	0	0	89.8	0.0	86.6
01:41.36	531.117	32.9	1.78	RUN 8	566	65	101	136	0	0	101	136	0	0	0	0	89.8	0.0	86.6
01:51.20	531.026	33.2	2.58	RUN 8	562	68	101	141	0	0	101	141	0	0	0	0	89.8	0.0	86.6
02:01.05	530.935	33.8	3.96	RUN 8	556	75	101	149	0	0	101	149	0	0	0	0	89.8	0.0	86.6
02:11.31	530.838	34.6	4.97	RUN 8	547	79	97	146	0	0	97	146	0	0	0	0	89.8	0.0	86.6
02:21.16	530.743	35.4	5.40	RUN 8	538	81	100	143	0	0	100	143	0	0	0	0	89.8	0.0	86.6
02:31.41	530.642	36.3	3.87	RUN 7	485	82	95	136	0	0	95	136	0	0	0	0	89.8	0.0	86.6
02:41.25	530.543	36.9	4.14	RUN 7	479	76	80	115	0	0	80	115	0	0	0	0	89.8	0.0	86.6
02:51.10	530.442	37.3	0.62	RUN 6	360	76	101	112	0	0	101	112	0	0	0	0	89.8	0.0	86.6
03:01.35	530.336	37.4	0.56	RUN 6	359	61	68	77	0	0	68	77	0	0	0	0	89.8	0.0	86.6
03:11.19	530.235	37.5	0.24	RUN 6	359	61	101	71	0	0	101	71	0	0	0	0	89.8	0.0	86.6
03:21.04	530.133	37.5	-0.15	RUN 6	359	60	101	68	0	0	101	68	0	0	0	0	89.8	0.0	86.6
03:31.29	530.027	37.5	2.90	RUN 7	455	58	101	93	0	0	101	93	0	0	0	0	89.8	0.0	86.6
03:41.13	529.923	38.1	3.89	RUN 7	468	58	101	102	0	0	101	102	0	0	0	0	89.8	0.0	86.6
03:51.39	529.811	38.9	4.78	RUN 7	460	51	101	106	0	0	101	106	0	0	0	0	89.8	0.0	86.6
04:01.23	529.702	39.4	2.24	RUN 6	344	44	101	103	0	0	101	103	0	0	0	0	89.0	0.0	86.6
04:11.07	529.592	39.9	3.05	RUN 6	341	26	101	74	0	0	101	74	0	0	0	0	89.8	0.0	86.6
04:21.32	529.475	40.4	2.86	RUN 6	337	24	98	70	0	0	98	70	0	0	0	0	89.8	0.0	86.6
04:31.16	529.362	40.8	1.99	RUN 6	334	17	101	59	0	0	101	59	0	0	22	0	89.8	0.0	86.6
04:41.01	529.248	41.0	1.00	RUN 6	333	19	101	56	20	-7	101	56	19	0	23	8	89.0	0.0	86.6
04:51.26	529.129	41.1	-0.24	RUN 6	332	22	101	57	2	-25	101	57	13	-3	2	-25	89.8	0.0	86.6
05:01.12	529.014	41.0	-1.27	RUN 6	332	23	101	58	27	-12	101	58	21	-3	43	15	89.0	0.0	86.6
05:11.37	528.895	40.7	-2.21	RUN 6	334	25	101	59	19	-3	101	59	19	-3	17	26	09.0	0.0	06.6
05:21.23	528.780	40.3	-1.66	RUN 6	337	27	101	60	12	-1	101	60	12	-1	13	27	09.0	0.0	06.6
05:31.07	528.666	40.1	-1.33	RUN 6	339	26	101	68	0	0	101	60	0	0	0	0	89.8	0.0	86.6
05:41.34	528.549	39.9	-0.82	RUN 6	341	23	101	68	0	0	101	60	0	0	0	0	09.0	0.0	86.6
05:51.20	528.436	40.0	2.38	RUN 7	449	39	101	97	0	0	101	97	0	0	0	0	89.8	0.0	86.6
06:01.04	528.323	40.5	2.63	RUN 7	446	43	101	100	0	0	101	100	0	0	0	0	89.8	0.0	86.6
06:11.29	528.203	40.9	2.71	RUN 7	443	44	101	98	0	0	101	98	0	0	0	0	89.8	0.0	86.6
06:21.13	528.087	41.4	2.44	RUN 7	441	48	101	96	0	0	101	96	0	0	0	0	89.8	0.0	86.6
06:31.38	527.967	41.4	-1.70	RUN 6	330	49	101	95	0	0	101	95	0	0	13	0	89.8	0.0	86.6
06:41.23	527.855	41.0	-2.82	RUN 6	332	38	101	62	3	-22	101	62	7	-2	3	-22	89.8	0.0	86.6
06:51.10	527.745	40.6	-0.32	RUN 7	422	47	101	86	6	-1	101	86	6	-1	2	29	89.0	0.0	86.6
07:01.36	527.631	40.6	0.40	RUN 7	445	50	101	94	0	0	101	94	0	0	0	0	89.0	0.0	06.6
07:11.22	527.520	40.7	0.38	RUN 7	445	46	101	93	0	0	101	93	0	0	0	0	89.8	0.0	86.6
07:21.07	527.410	40.8	0.53	RUN 7	444	43	101	95	0	0	101	95	0	0	0	0	89.0	0.0	86.6
07:31.33	527.295	40.9	0.79	RUN 7	444	40	101	95	0	0	101	95	0	0	0	0	89.8	0.0	86.6
07:41.18	527.184	41.0	0.63	RUN 7	443	37	101	95	0	0	101	95	0	0	0	0	89.8	0.0	86.6
07:51.02	527.073	41.1	0.34	RUN 7	443	34	101	92	0	0	101	92	0	0	0	0	89.8	0.0	86.6
08:01.27	526.957	40.7	-3.48	RUN 6	335	32	101	91	0	0	101	91	0	0	0	0	89.8	0.0	86.6
08:11.11	526.846	40.1	-5.20	RUN 5	266	22	101	62	0	0	101	62	0	0	0	0	89.8	0.0	86.6

when the brake outage percentages and brake outage distributions were varied. Between engineers A and B, buff forces were slightly higher (approximately 75 kips) for engineer A. For engineer C, however, buff forces decreased as the percentage of brake outages increased. As mentioned earlier, both engineers A and C were not experienced in operating the coal train. Thus, buff forces decreased at the later coal train simulations after engineer C had gained some experience with the LETS coal train consist. For the van train, buff forces increased as the percentage of brake outage increased during dynamic braking operations. Engineers A and C increased buff forces by 50 kips between the two 15% brake outages. The higher force occurred in brake outage distribution #2, where the outages were located toward the center of the consist. There were no significant differences in buff force between the two 15% brake outages for engineer B. Finally, the results showed no significant difference in draft forces for either the coal or van train during power braking or dynamic braking operations for any of the brake outage conditions tested.

To understand the effect that the percentage of brake outage had on the performance of braking operations, the amount of brake pipe pressure reduction was analyzed. The brake pipe reductions for all the simulations are summarized in Table 6. According to the table, brake pipe pressure reduction increased slightly as the percentage of brake outage increased for most of the coal train simulations. However, there was a significant increase in brake pipe pressure reduction during power braking operations performed by engineer C (from 14.2 psi for no brake outage to 20.1 psi for a 20% brake outage in the coal train consist). As shown in Figures C-1 to C-4, engineer C was operating closer to the maximum allowable speed while performing power braking operations on the coal train consist with higher percentages of brake outage. Thus, the better control in speed was achieved at the cost of increased brake pipe pressure reduction. There was no significant difference in brake pipe pressure reduction for power braking operations performed by engineers A and C for increasing percentage of brake outage in the van train consist. However, the brake pipe pressure reduction was decreased from 14.8 psi for no brake outage to 9.2 psi for a 20% brake outage for the power braking operations performed by engineer B. According to Figure B-9, engineer B was operating at a speed much lower than the maximum allowable speed during the initial run of the van train consist. On later runs, engineer B was more familiar with the van train consist and had a better control of the speed during braking operations of the van train. Because the coal train carried higher loading, it required more brake pipe pressure reduction during both types of braking operations when compared with the van train. Because the engineers became more familiar with the operation of the van train at later simulations, all three engineers required less brake pipe pressure reduction as the percentage of brake outages increased in the van train consist. There was a significant difference in brake pipe pressure reduction for the dynamic braking operations of the van train consist performed by engineers B and C. The brake pipe pressure reduction was decreased from 6.5 psi for no brake outage to 0 psi for a 20% brake outage. In reference to Table 4, the higher powered locomotives were used in the consists with higher percentages of brake outage, and the type of locomotives used in the coal train consist had more power than the locomotives used in the van train consist. The increase in power provided easier handling of the train. According to the three engineers, although there was no significant difference in handling between the different percentages of brake outage for the van train, handling was more difficult as the percentages of brake outage increased for the coal train.

Table 6. Summary of Brake Pipe Pressure Reduction (BPPR)

Consist	Braking Operation	Brake Outage % and Distribution #		BPPR (psi)		
				A	B	C
Coal Train	power braking	0	n/a	16.4	16.3	14.2
		15	1	17.8	18.4	16
		15	2	16.8	17	18
		20	3	17.2	18.7	20.1
	dynamic braking	0	n/a	10.1	11.2	10.1
		15	1	9.6	12	13.7
		15	2	15.8	11.5	11.1
		20	3	13.7	12.9	13.4
Van Train	power braking	0	n/a	9	14.8	10.8
		15	1	8.6	10.1	9.7
		15	2	8.5	9.4	10.1
		20	3	8.9	9.2	10.1
	dynamic braking	0	n/a	9.9	6.5	6.5
		15	1	6.5	6.5	6.5
		15	2	6.5	6.5	0
		20	3	6.5	0	0

A more nearly level segment of track from the Delaware & Hudson Railway (MP 544 to MP 536, see Figure 3) was used to perform a power braking operation with a coal train consist and no brake outage. The simulation was performed by engineer A. A summary of the results is shown in Figure 4. According to Figures A-1 and 4, the speed was held almost constant during the entire simulation between mile posts 544 and 536 whereas the speed varied between 24 and 40.3 mph between mile posts 532 and 523 where the grade was much higher. The draft forces were also lower for simulation performed on a more level track. Although the buff forces were quite small during both runs, buff forces were slightly higher when the train was going over a small bump on the more level segment of track.

Each engineer was operating the train in the order as listed in Table 1. Coal train simulations were performed before van train simulations. Simulations with power braking operations were performed before simulations with dynamic braking operations. Also, simulations with lower percentages of brake outage were performed prior to those with higher percentages of brake outage. Since the engineers were not totally familiar with the operations of one or both consists initially, the handling difficulties for the engineers usually decreased in the later simulations with the same consist. As shown in Table 6, during the dynamic braking operations, two engineers did not use the air brake during braking operations for the van train consist. Neither engineer B nor C required any brake pipe pressure reduction to control the speed while performing dynamic braking on a van train consist with 20% brake outage. Further, engineer C did not apply any brake pipe pressure reduction while performing dynamic braking on a van train consist with 15% brake outage of distribution #2. However, as shown in Figures B-16, C-15 and C-16, higher buff forces occurred with no brake pipe pressure reduction. Operation of the coal train with dynamic braking required much more skill because the weight of the coal train was very high, thus producing much higher buff forces on the downgrade which could result in severe run-ins. Although the engineers agreed that the use of dynamic braking required more skill and lead time, they also agreed that the train speed was much easier to control with the dynamic brake. To avoid the run-in situation due to heavier load, the engineer always applied the air brake prior to the dynamic brake when operating the coal train. It was critical to set up the air brake pressure properly when cresting the hill while operating a coal train consist with dynamic braking. On the van train, however, the dynamic brake was used to start the braking operations and then the air brake was applied when required to control the speed. All of the engineers agreed that variation in brake outage distribution in the two 15% brake outages did not affect the handling difficulties of braking operation.

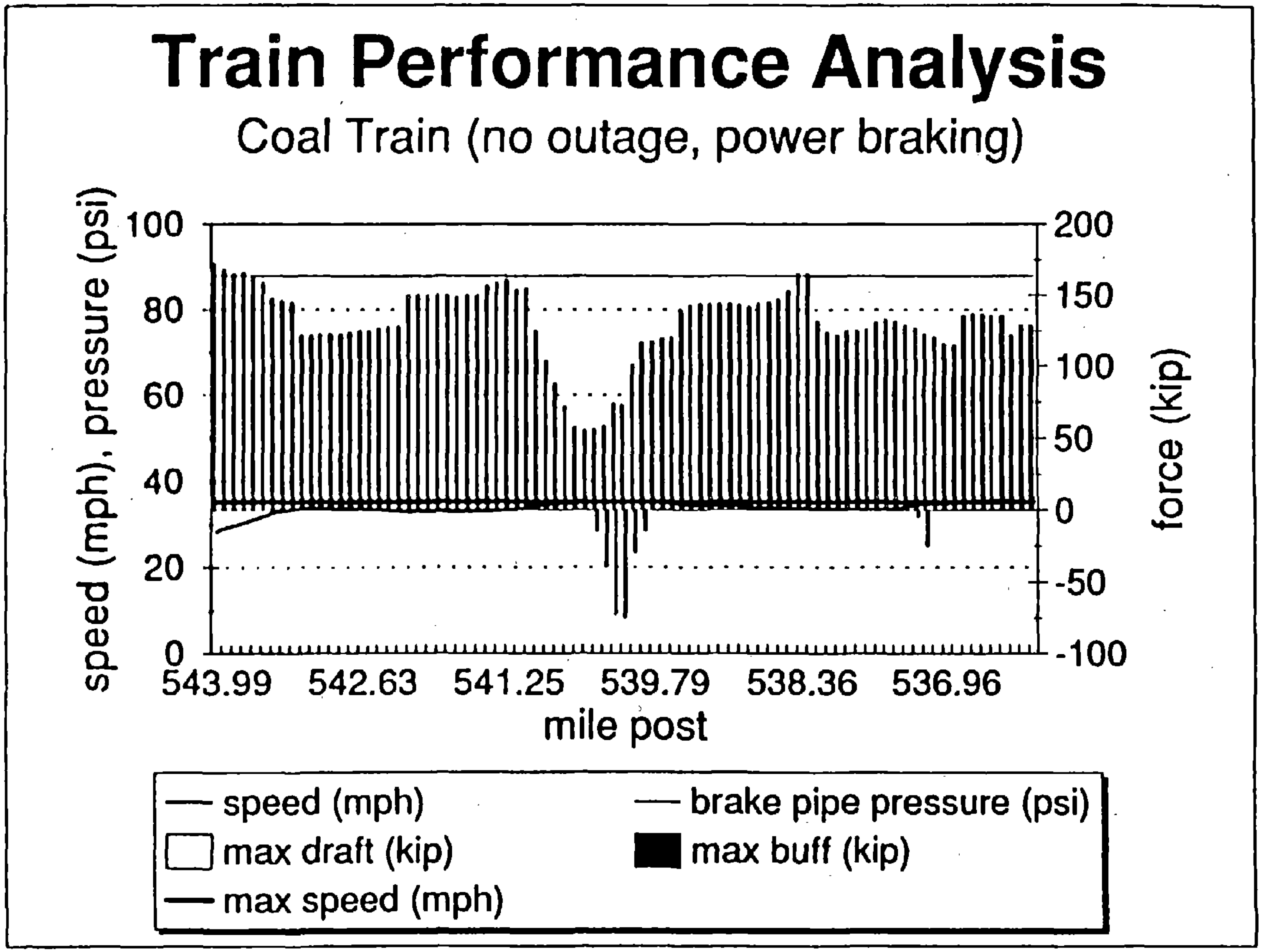

Figure 4. Summary of Results for a Coal Train Power Braking Operation with No Brake Outage

Conclusions

All three engineers performed the braking operations without significantly exceeding the maximum allowable safety limits for all train simulations. Although simulations with less difficult situations were performed first because of the lack of familiarity with the type of consist or braking operations during the first simulation, the overall performance of the engineers was consistent throughout the simulations. The engineers had no significant difficulties in controlling the speed for all runs.

While buff forces were very small during power braking operations for both consists, they became significant when dynamic braking was applied. Buff forces could be as high as 200 kips during dynamic braking operations for a coal train consist. The variation in brake outage percentages and brake outage distributions had no significant effect on buff forces with coal train consist simulations. For dynamic braking with the van train, buff forces increased as the percentage of brake outage increased. The braking operation with the 20% brake outage was on the edge of handling difficulties. There were no significant differences in draft forces for either the coal train or the van train during power braking and dynamic braking operations for the different percentages and distributions of brake outages.

Although speed was easier to control with the dynamic brake, braking operations using the dynamic brake required more skill and lead time. Performing braking operations with only the dynamic brake, without any aid of the power brake, would be expected to be accompanied by a significant increase in buff forces. Overall, the handling of the coal train required more attention than the handling of the van train.

Appendix A

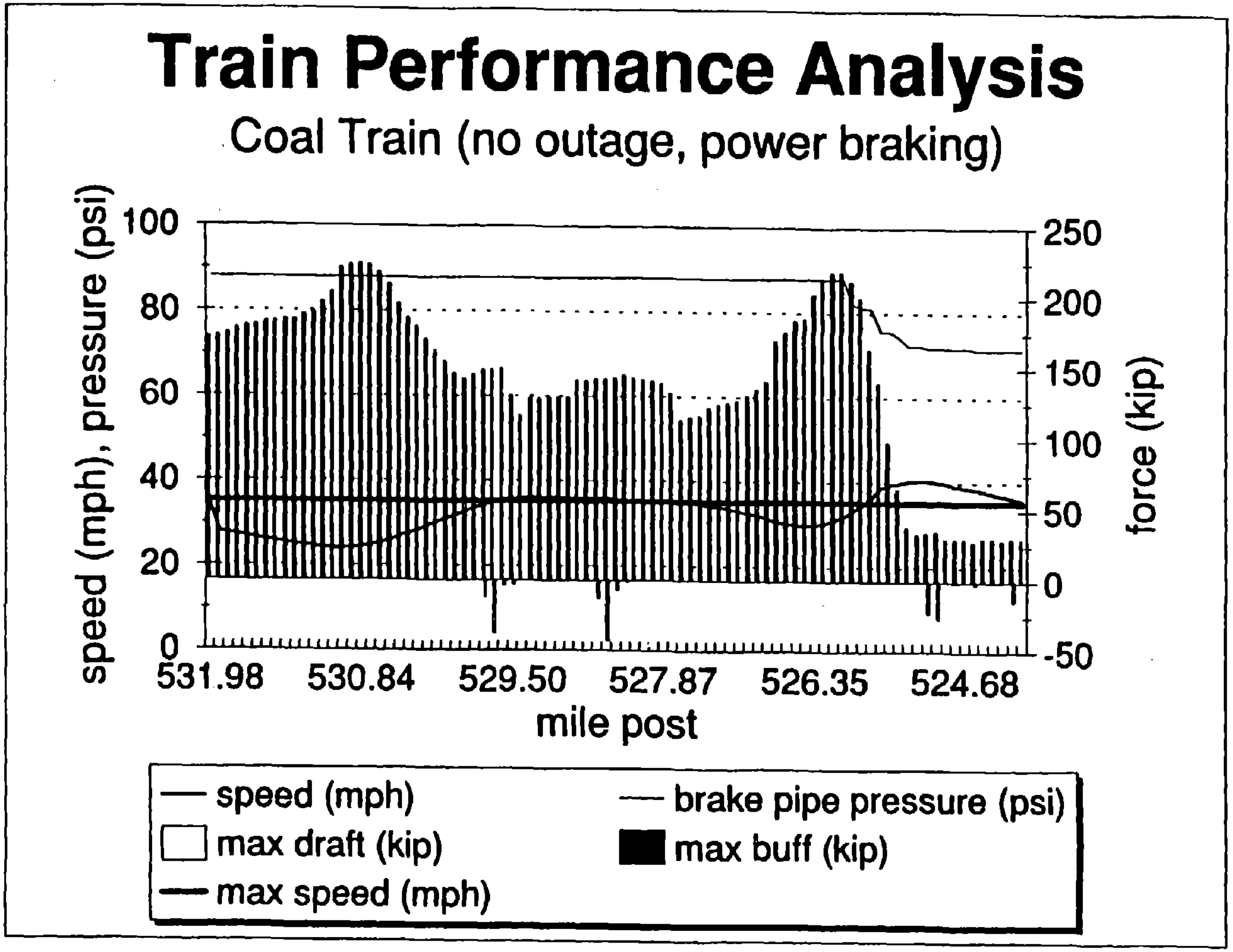

Figure A-1. Results for a Coal Train Power Braking Operation with No Brake Outage

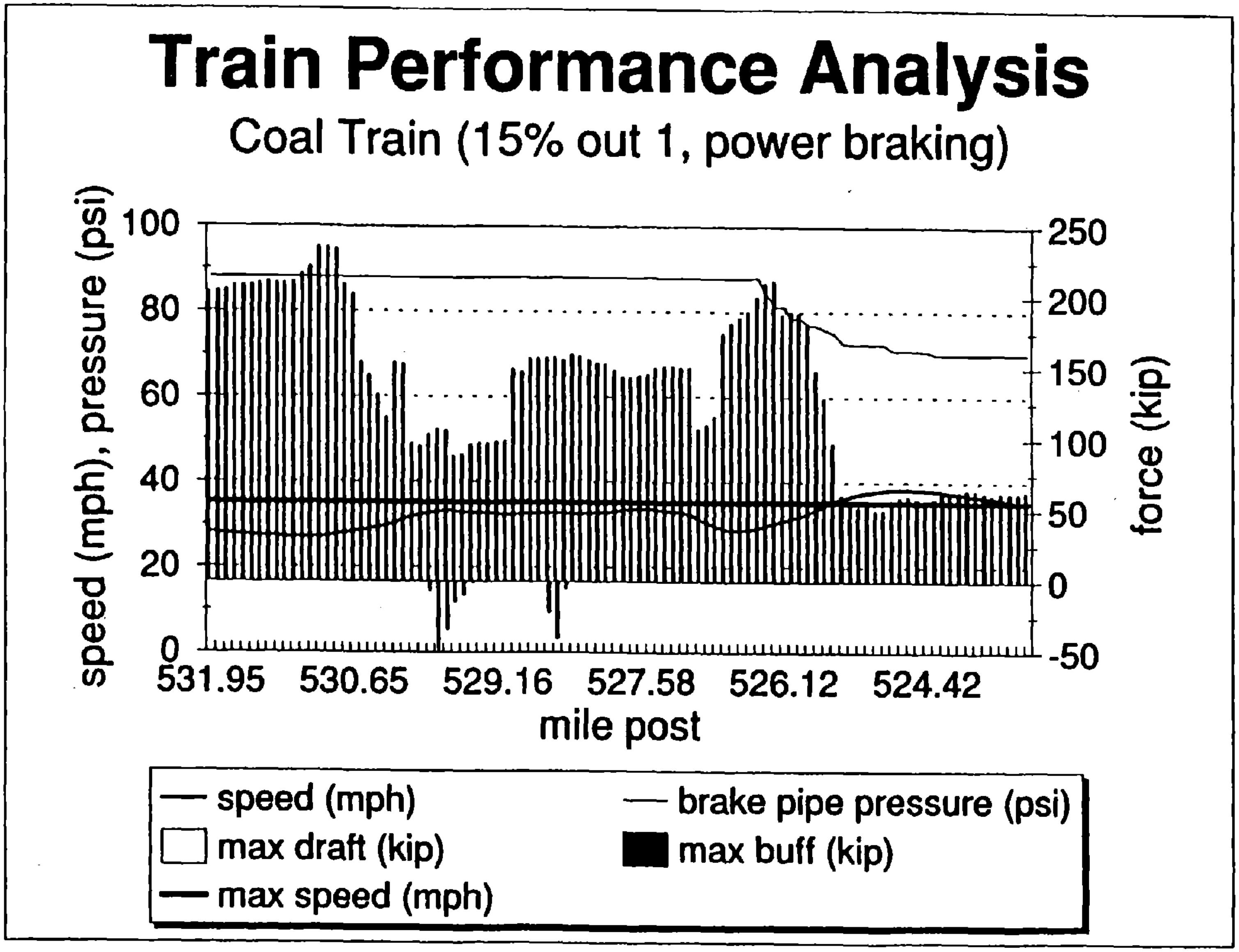

Figure A-2. Results for a Coal Train Power Braking Operation with #1 at 15% Brake Outages

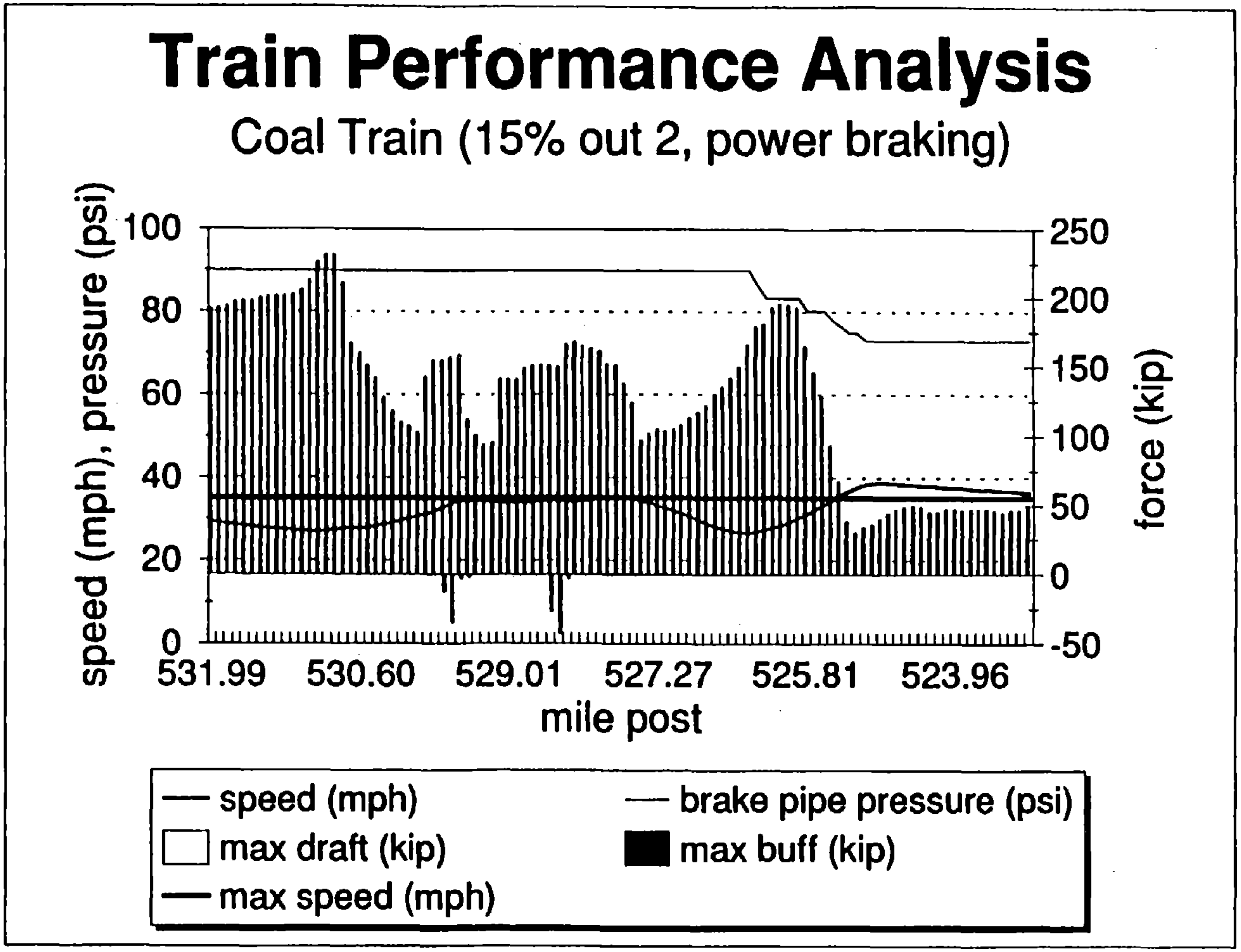

Figure A-3. Results for a Coal Train Power Braking Operation with #2 at 15% Brake Outages

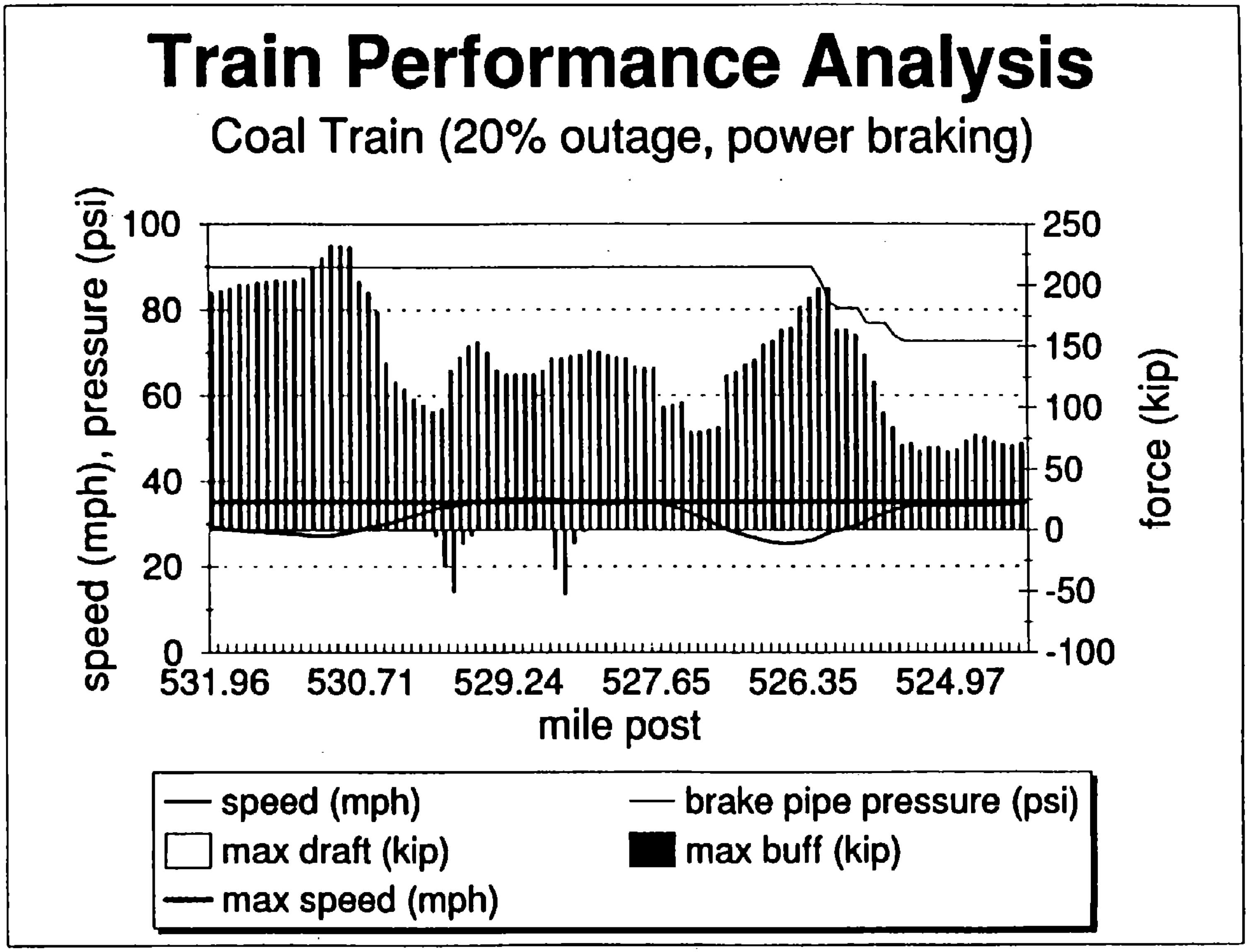

Figure A-4. Results for a Coal Train Power Braking Operation with 20% Brake Outages

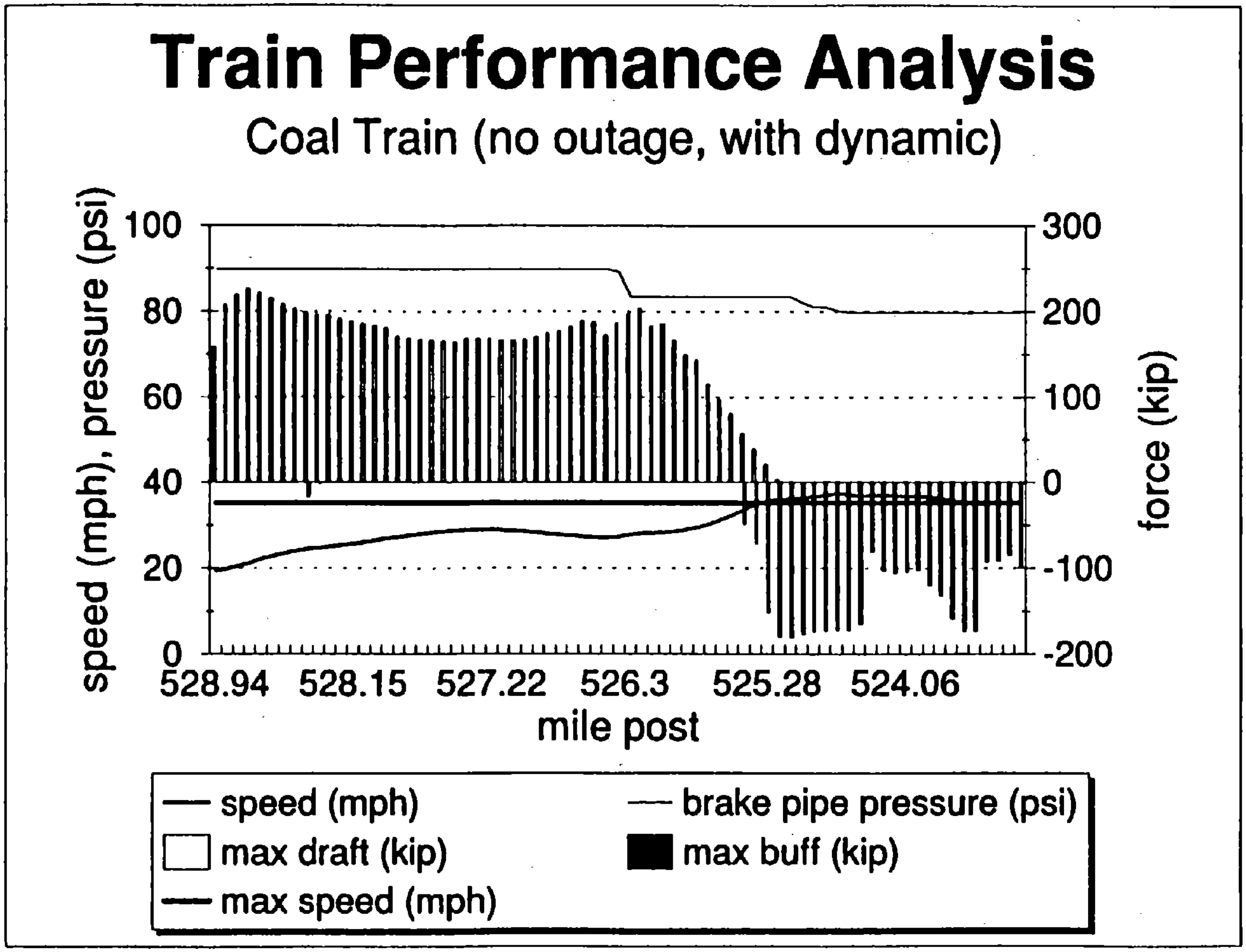

Figure A-5. Results for a Coal Train Dynamic Braking Operation with No Brake Outage

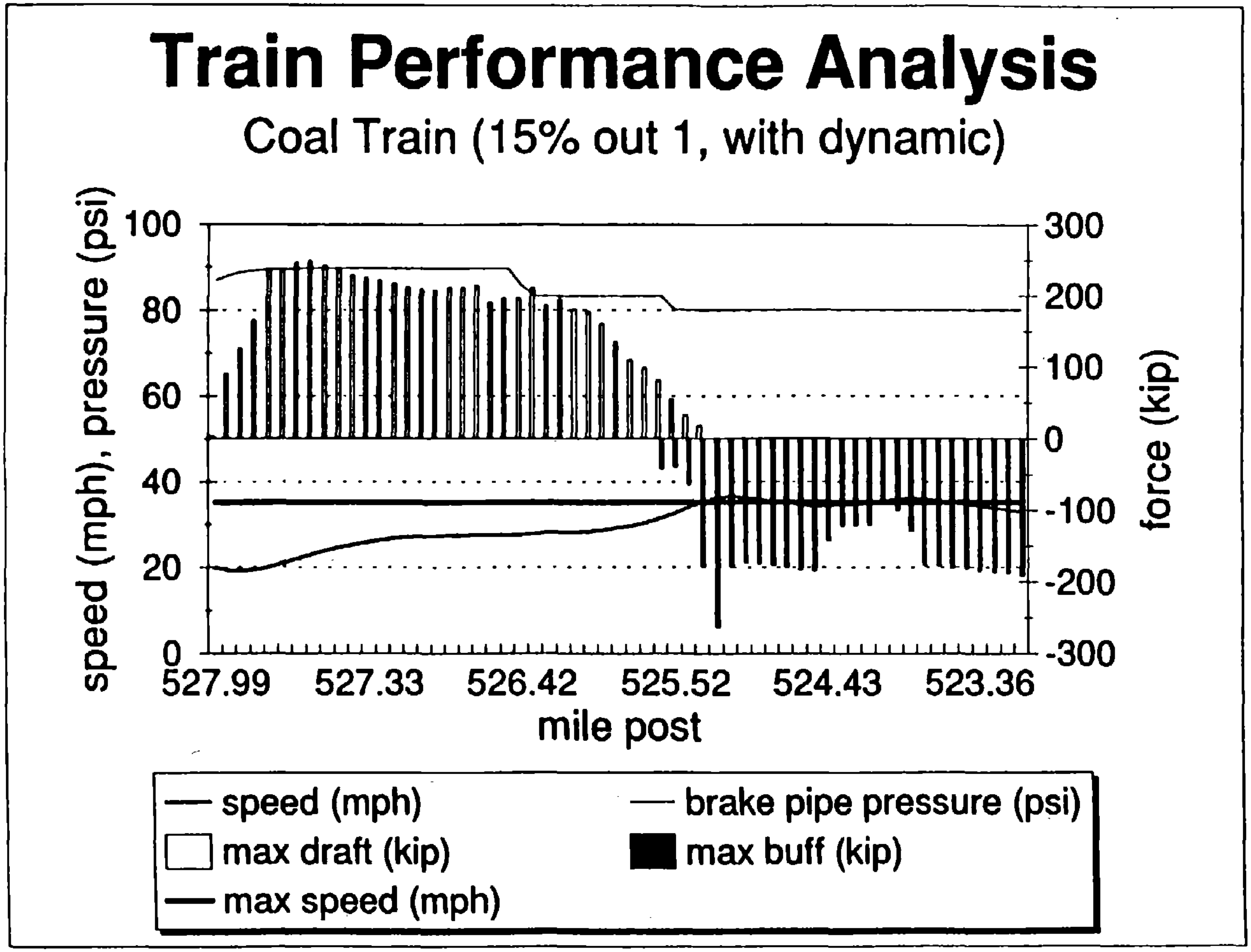

Figure A-6. Results for a Coal Train Dynamic Braking Operation with #1 at 15% Brake Outages

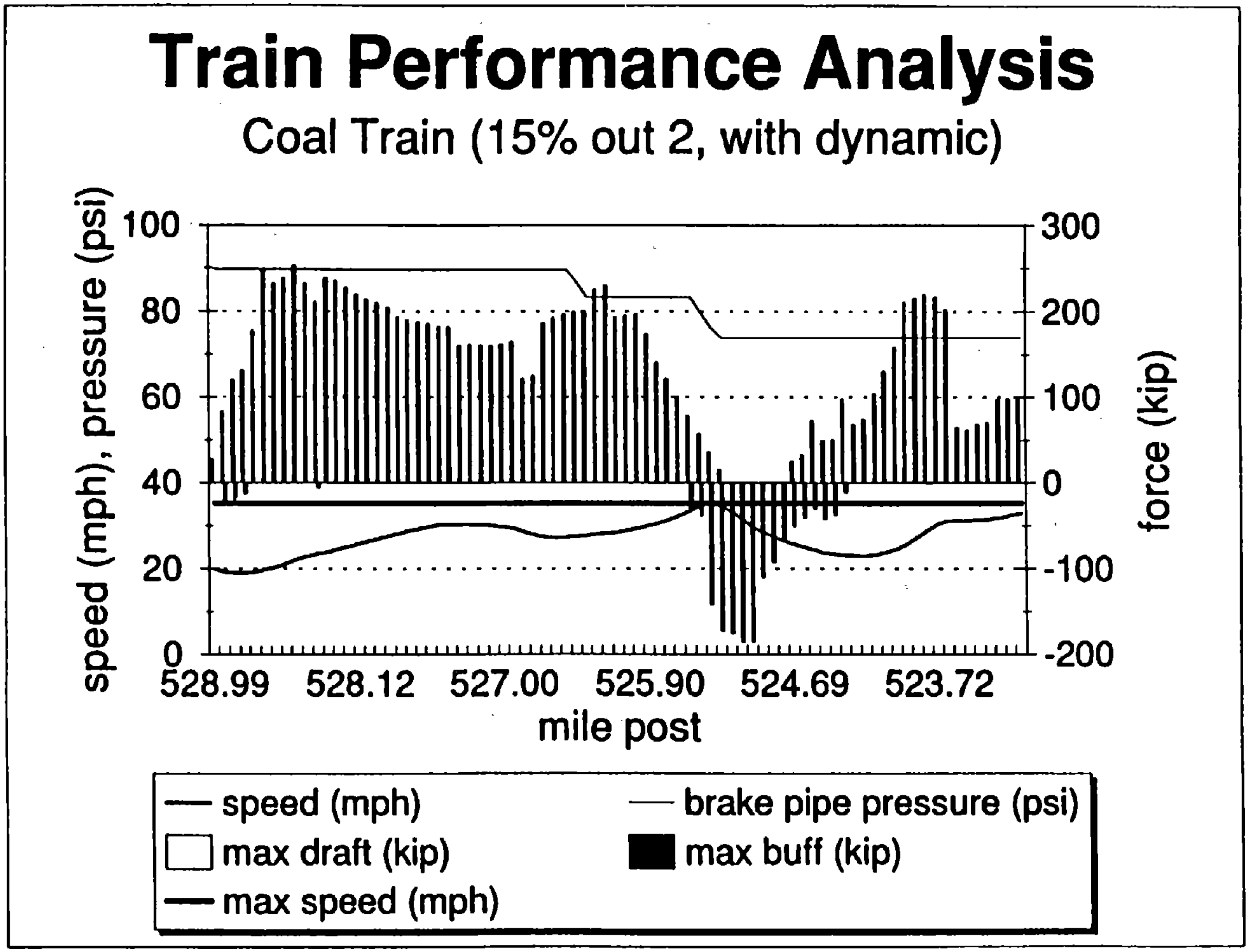

Figure A-7. Results for a Coal Train Dynamic Braking Operation with #2 at 15% Brake Outages

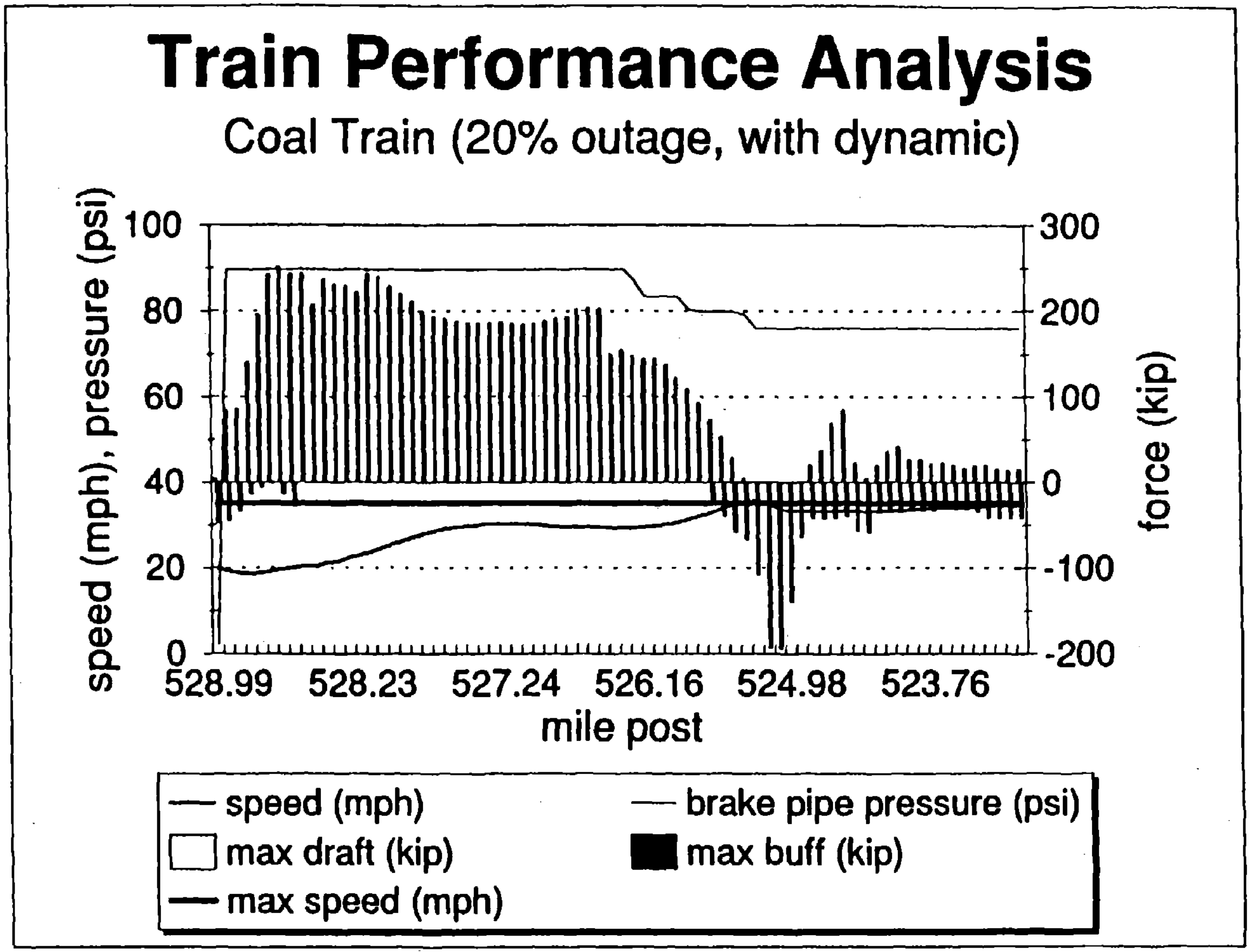

Figure A-8. Results for a Coal Train Dynamic Braking Operation with 20% Brake Outages

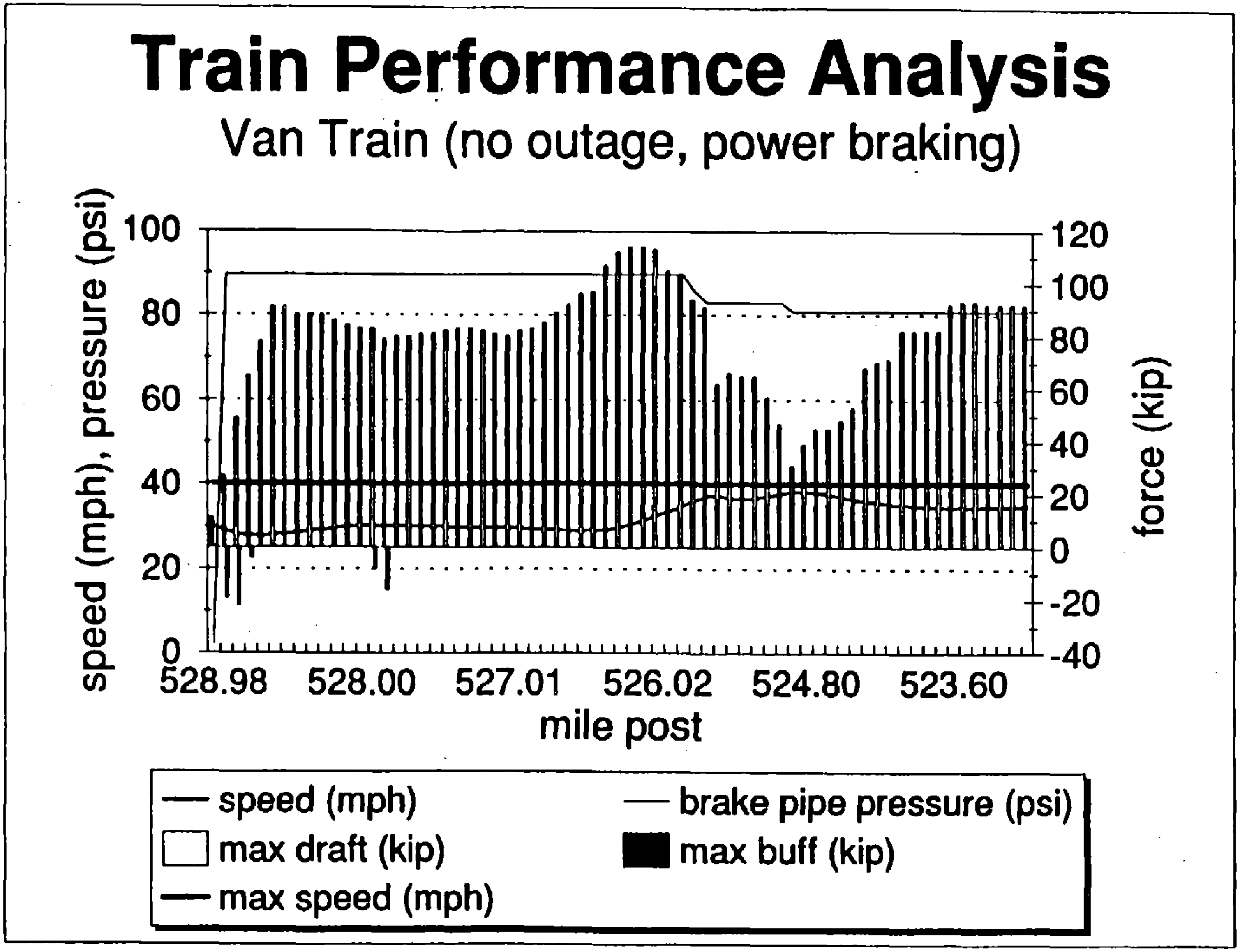

Figure A-9. Results for a Van Train Power Braking Operation with No Brake Outage

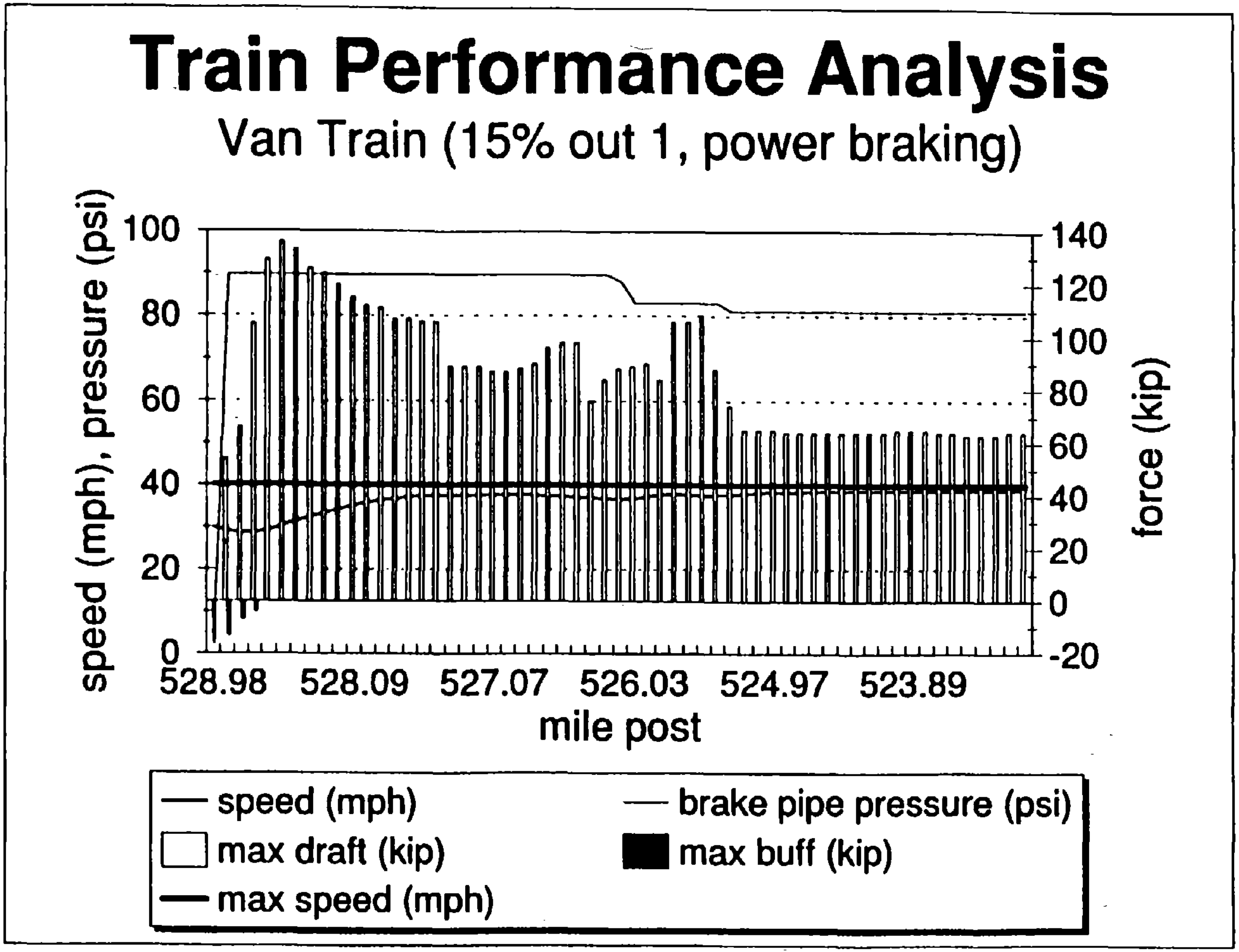

Figure A-10. Results for a Van Train Power Braking Operation with #1 at 15% Brake Outages

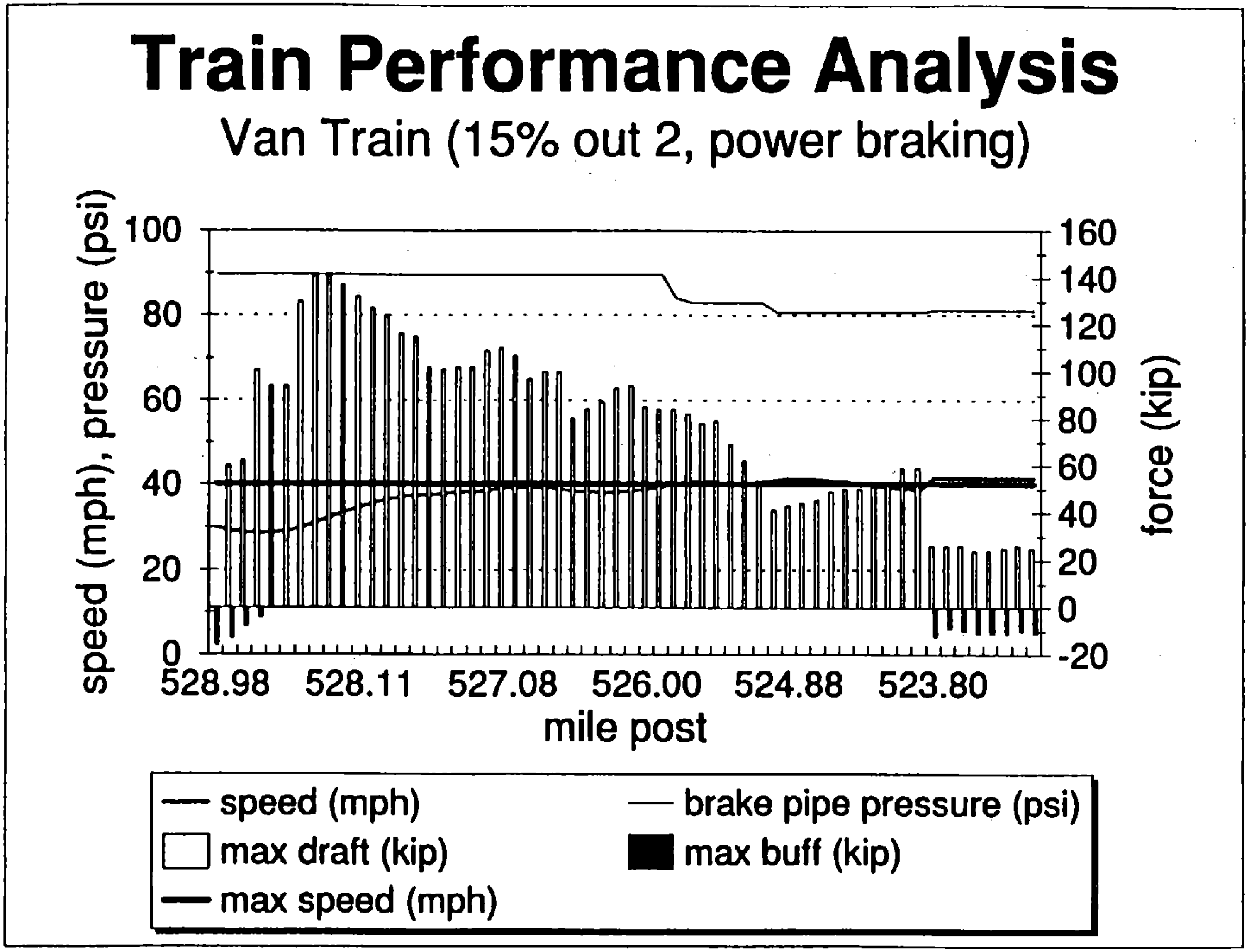

Figure A-11. Results for a Van Train Power Braking Operation with #2 at 15% Brake Outages

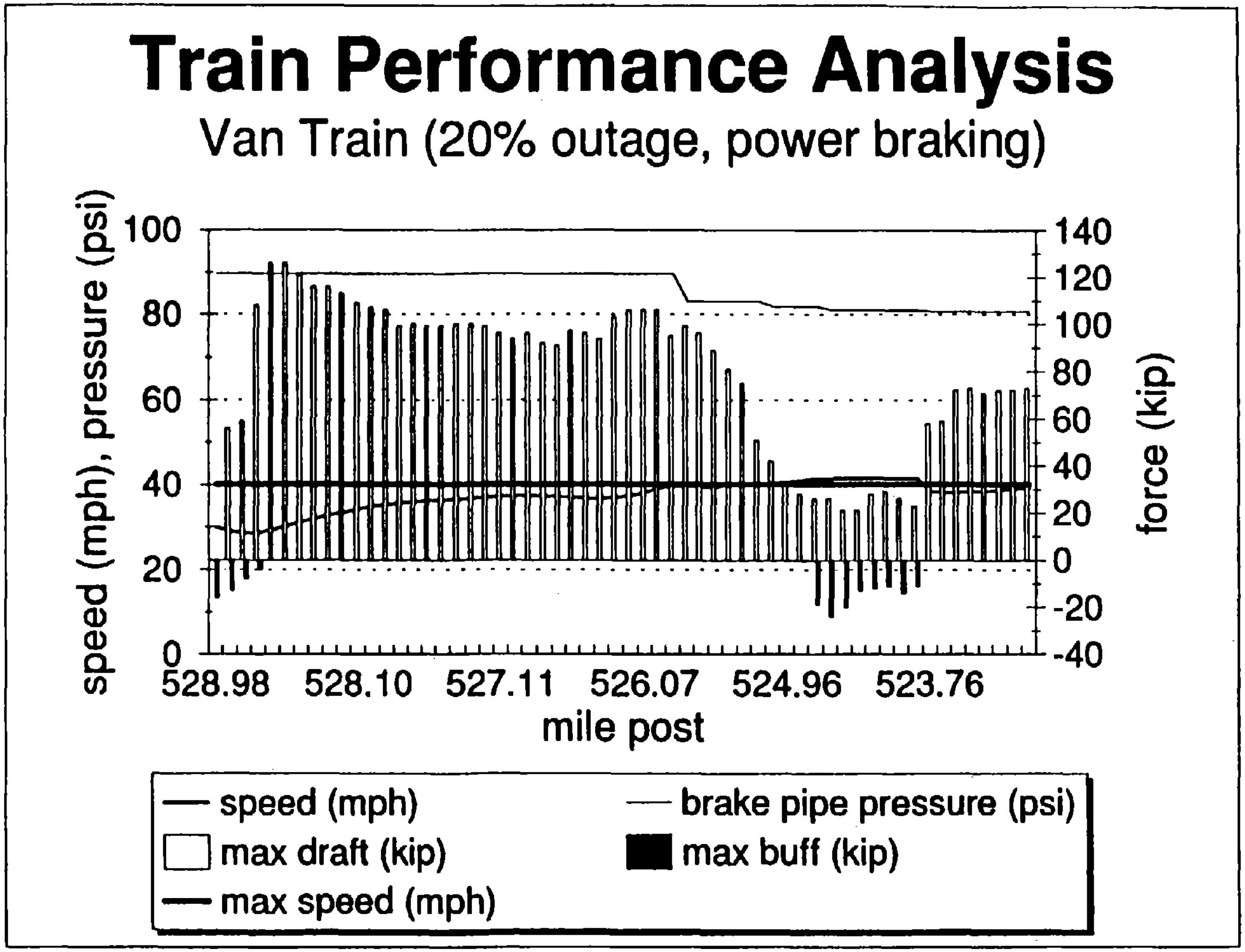

Figure A-12. Results for a Van Train Power Braking Operation with 20% Brake Outages

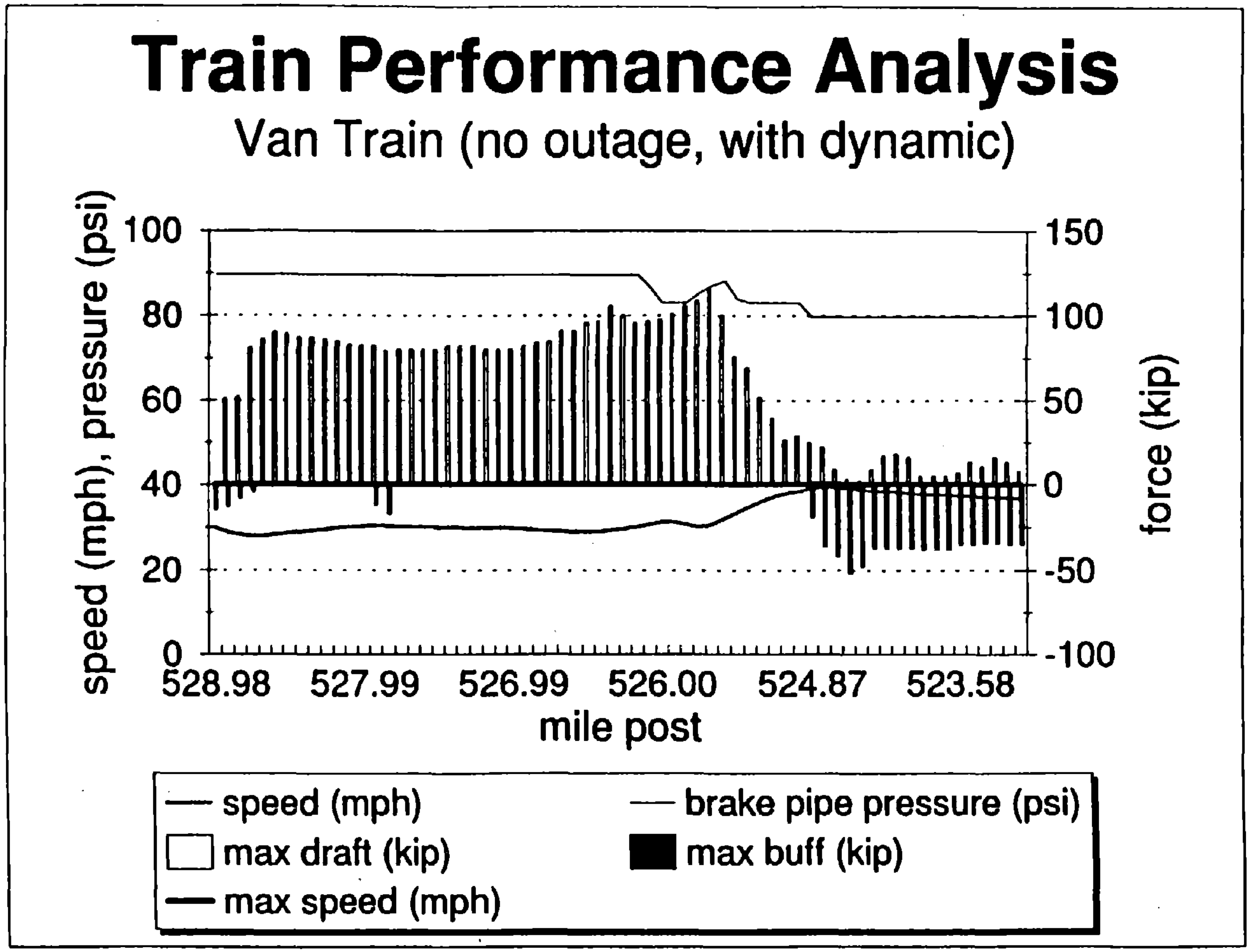

Figure A-13. Results for a Van Train Dynamic Braking Operation with No Brake Outage

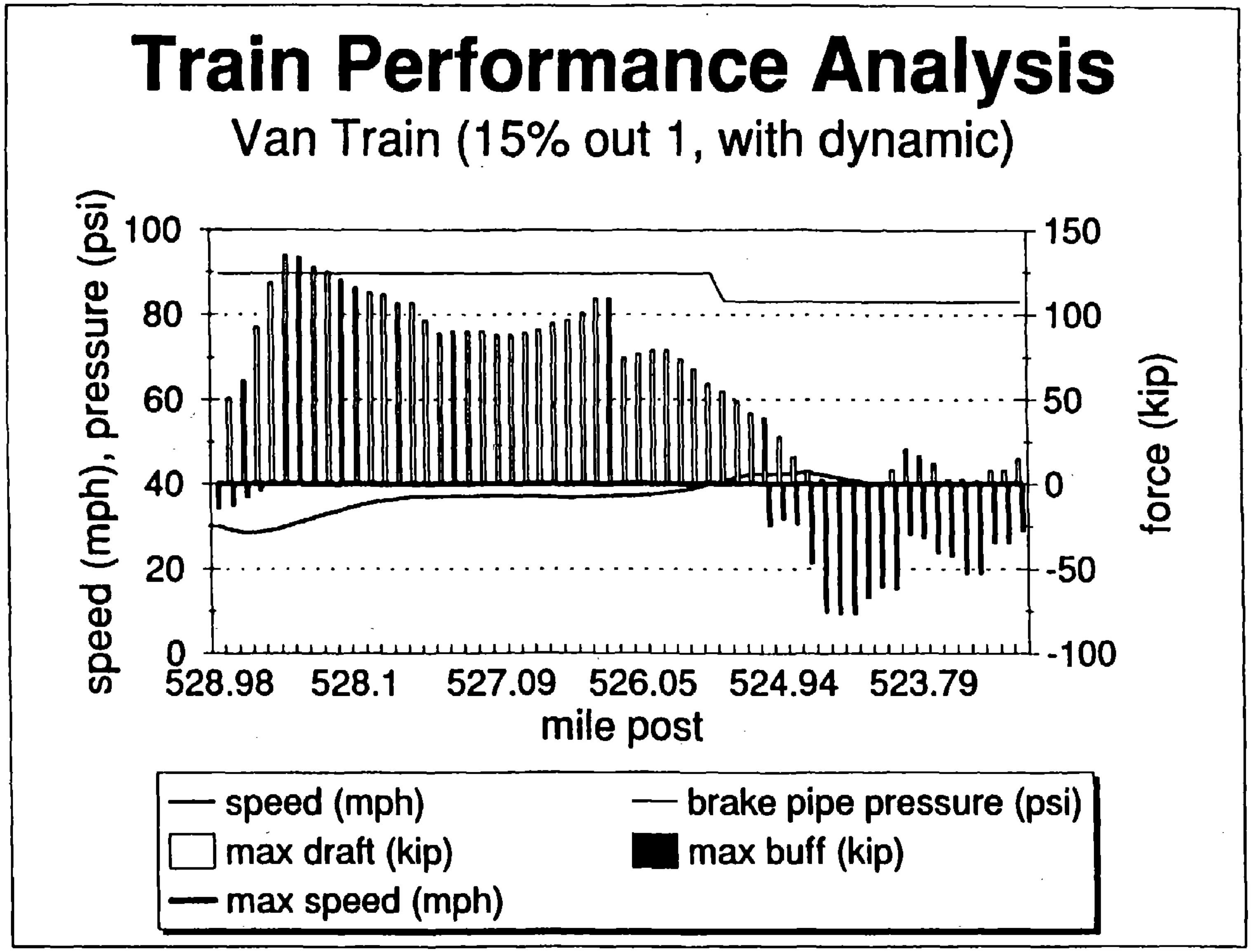

Figure A-14. Results for a Van Train Dynamic Braking Operation with #1 at 15% Brake Outages

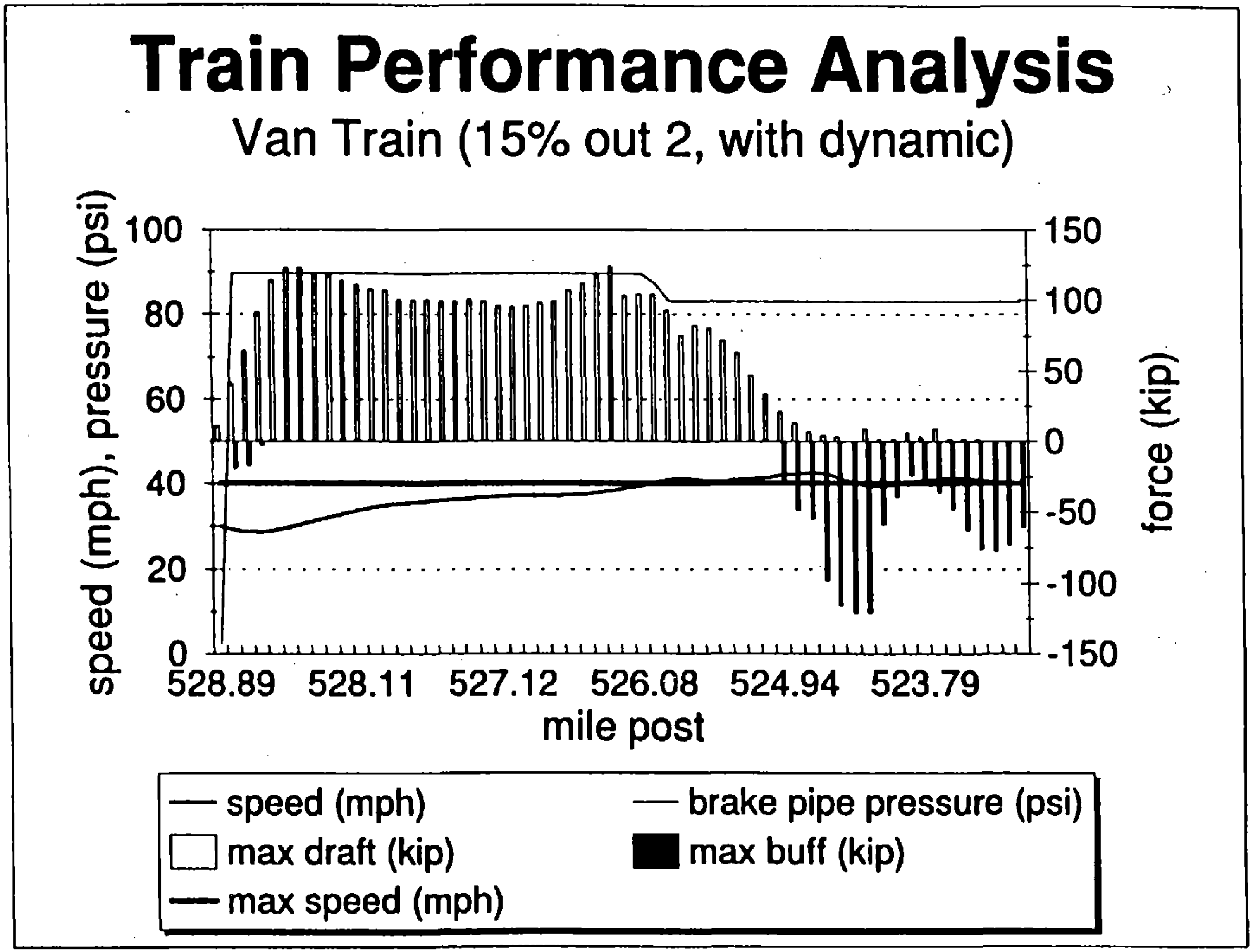

Figure A-15. Results for a Van Train Dynamic Braking Operation with #2 at 15% Brake Outages

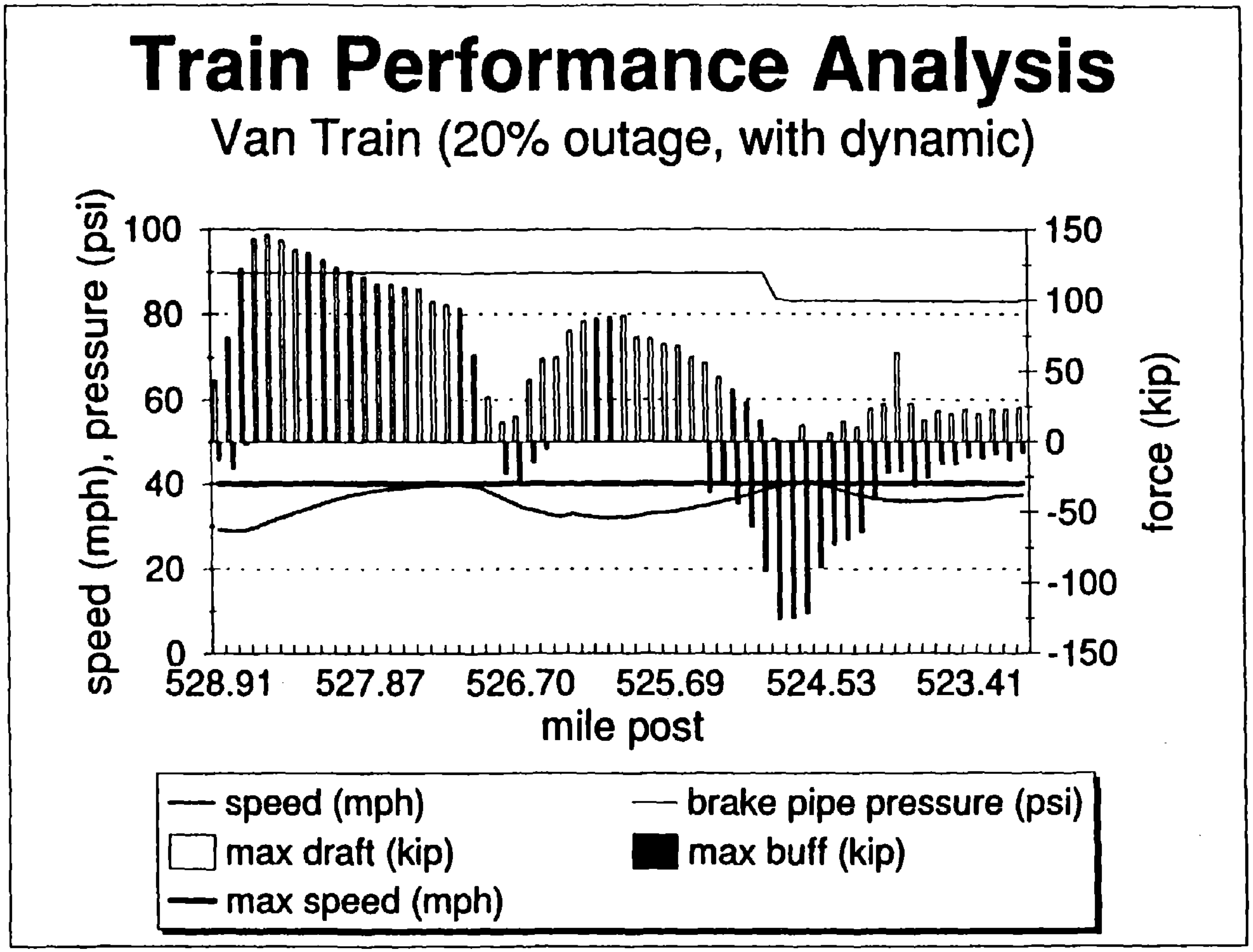

Figure A-16. Results for a Van Train Dynamic Braking Operation with 20% Brake Outages

Appendix B

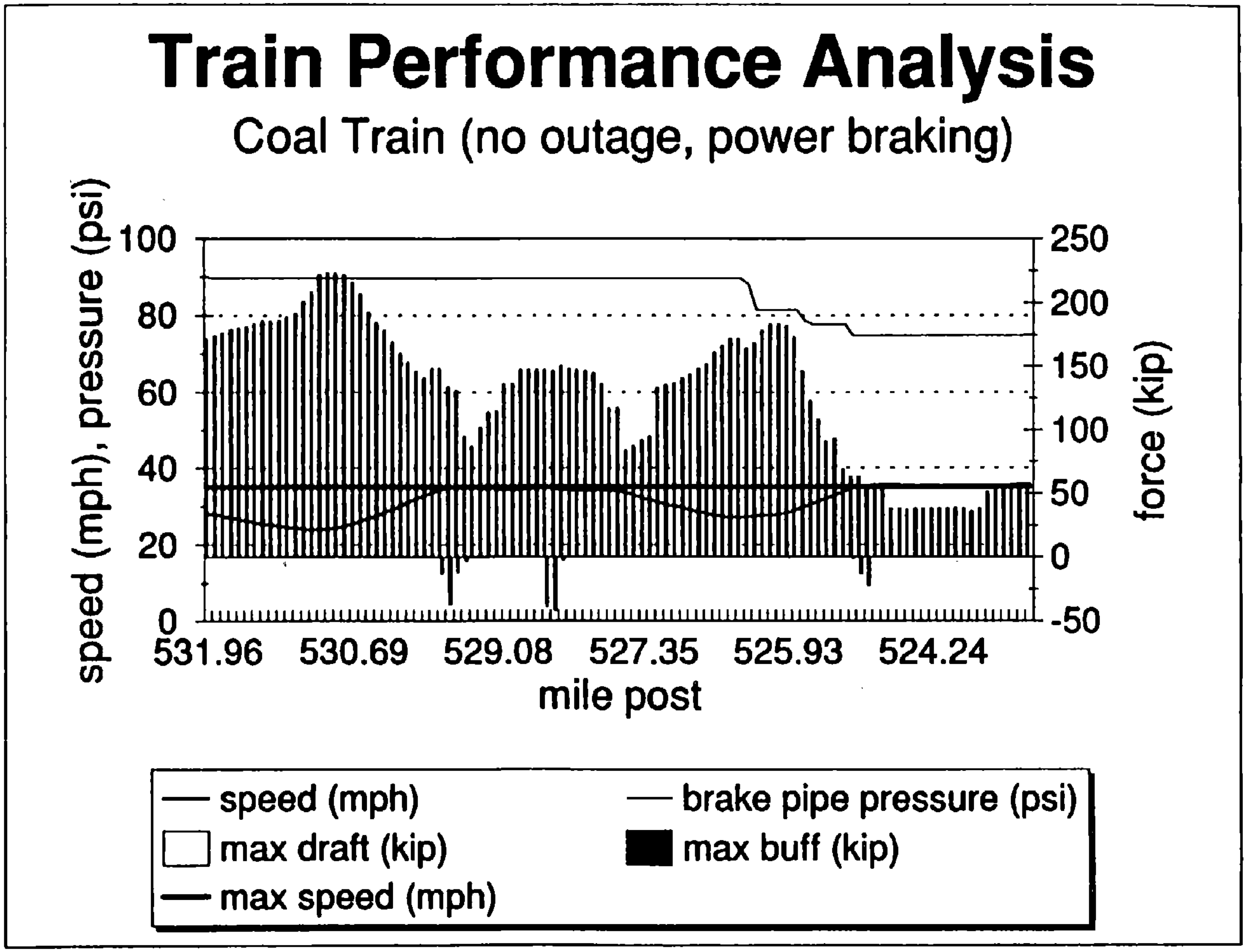

Figure B-1. Results for a Coal Train Power Braking Operation with No Brake Outage

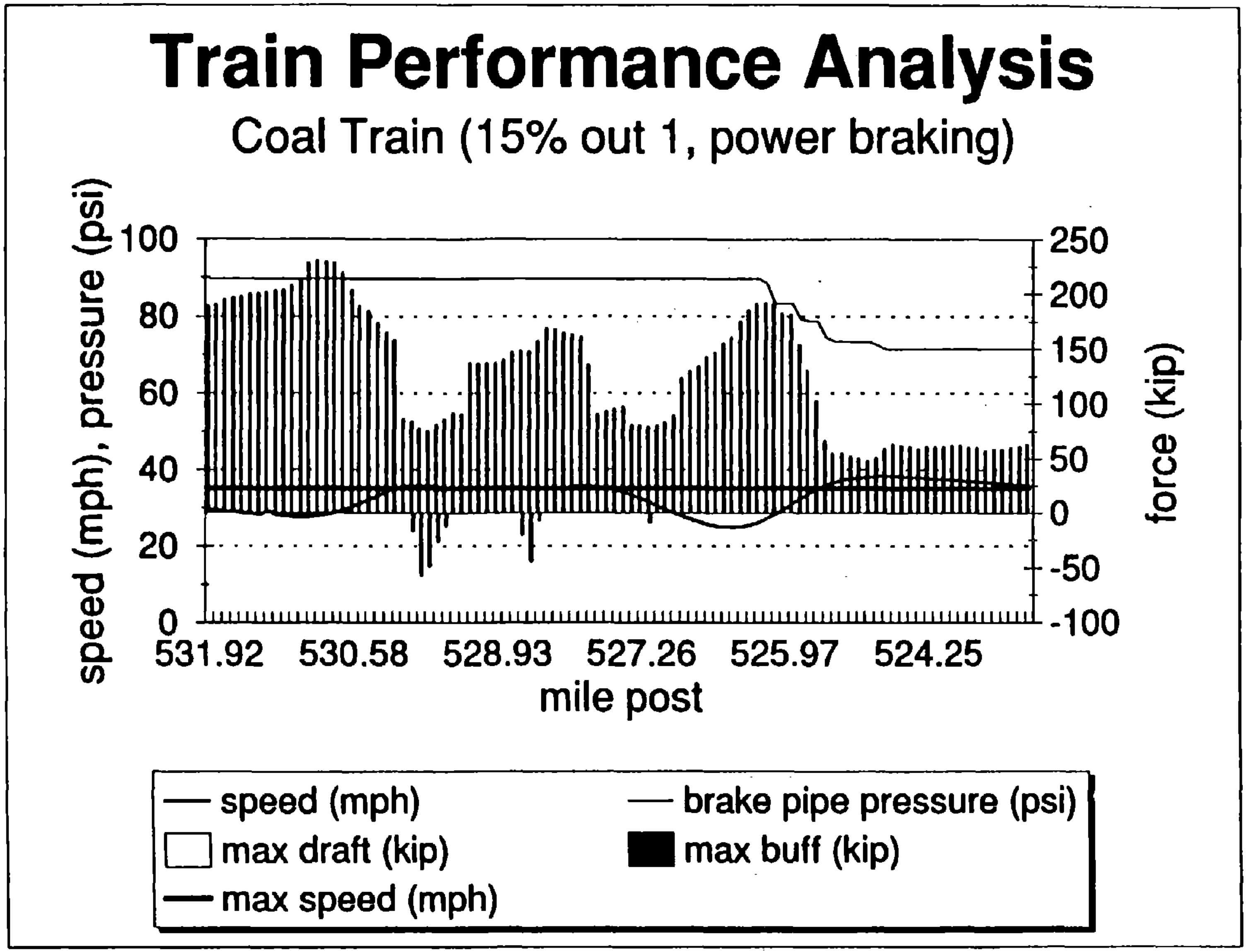

Figure B-2. Results for a Coal Train Power Braking Operation with #1 at 15% Brake Outages

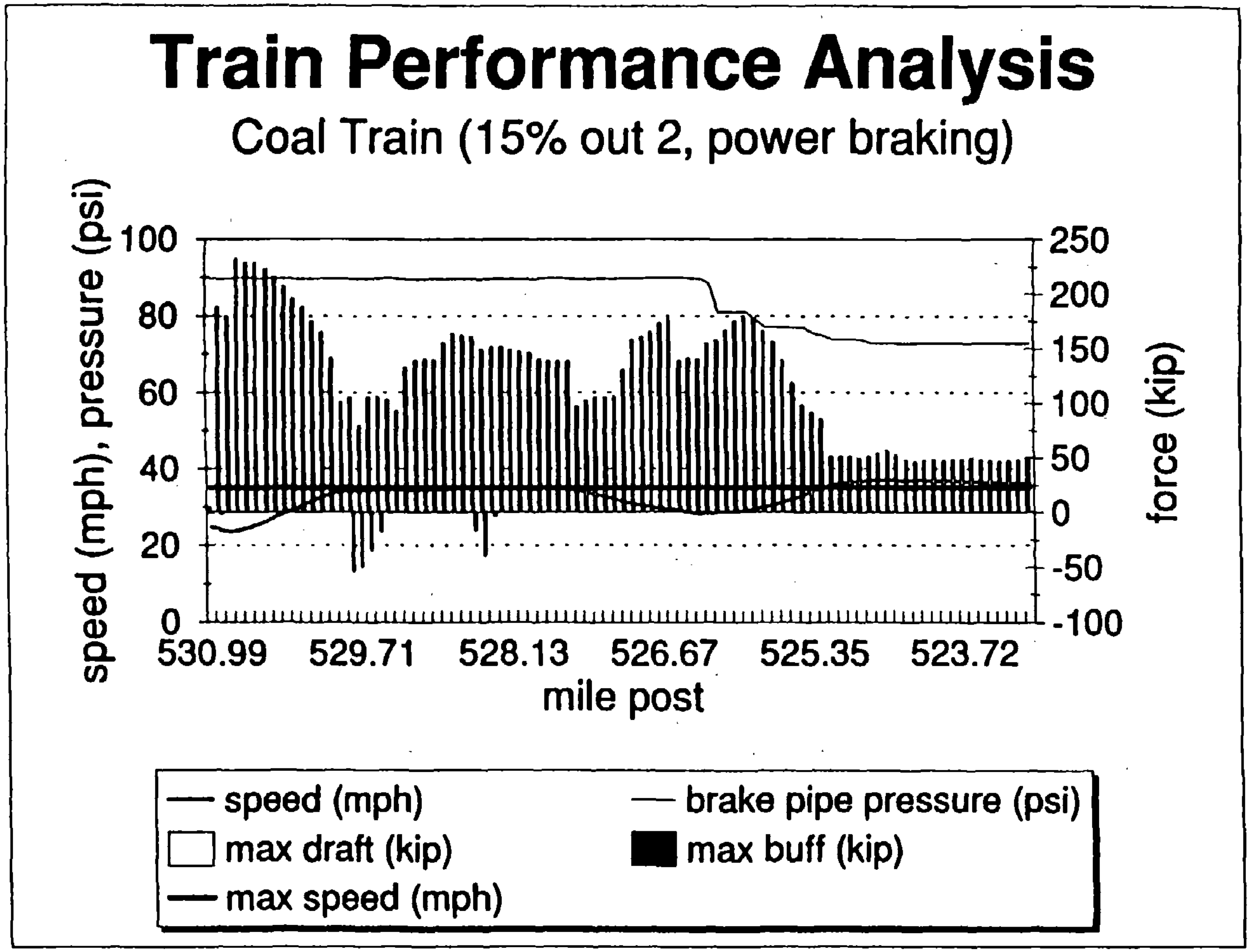

Figure B-3. Results for a Coal Train Power Braking Operation with #2 at 15% Brake Outages

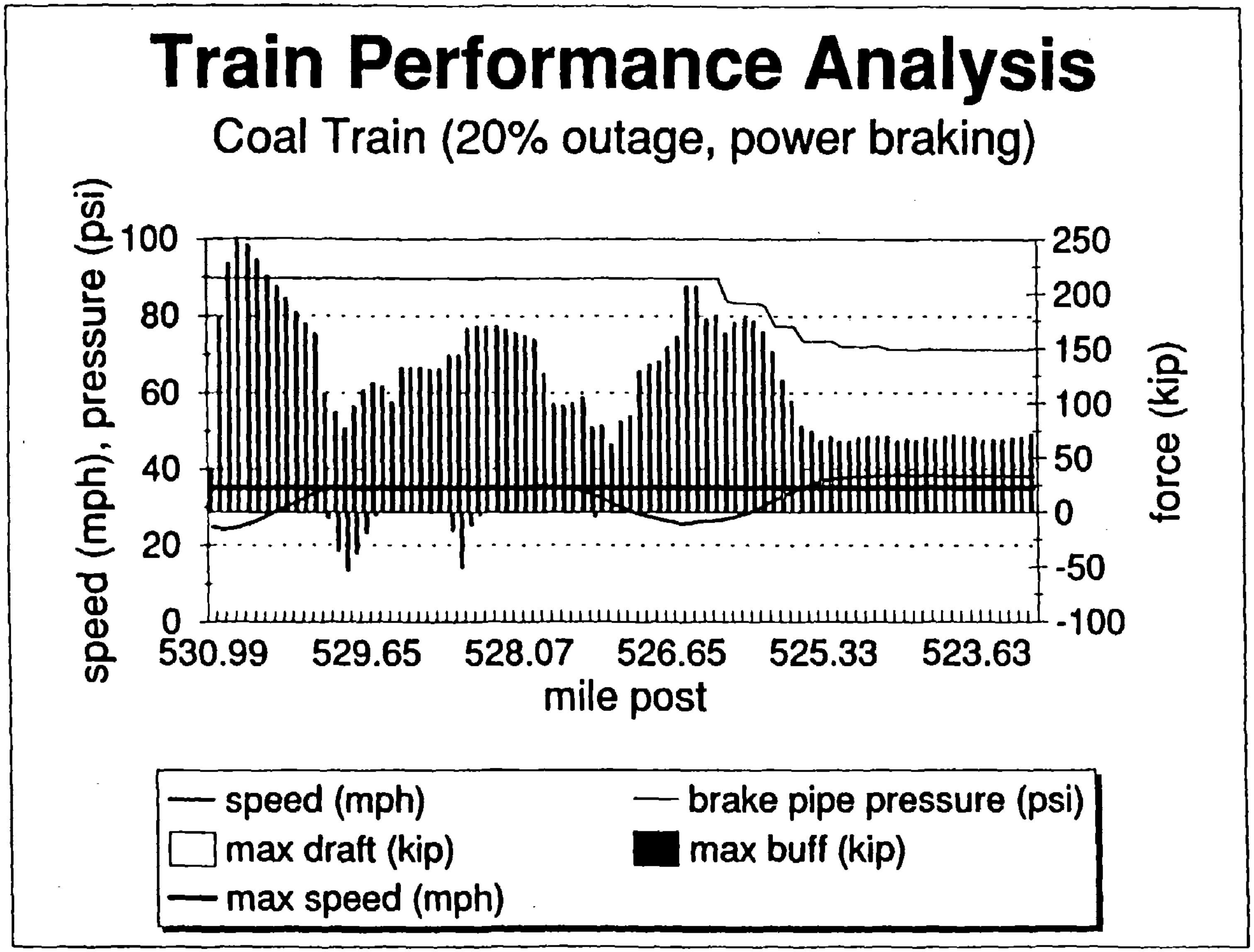

Figure B-4. Results for a Coal Train Power Braking Operation with 20% Brake Outages

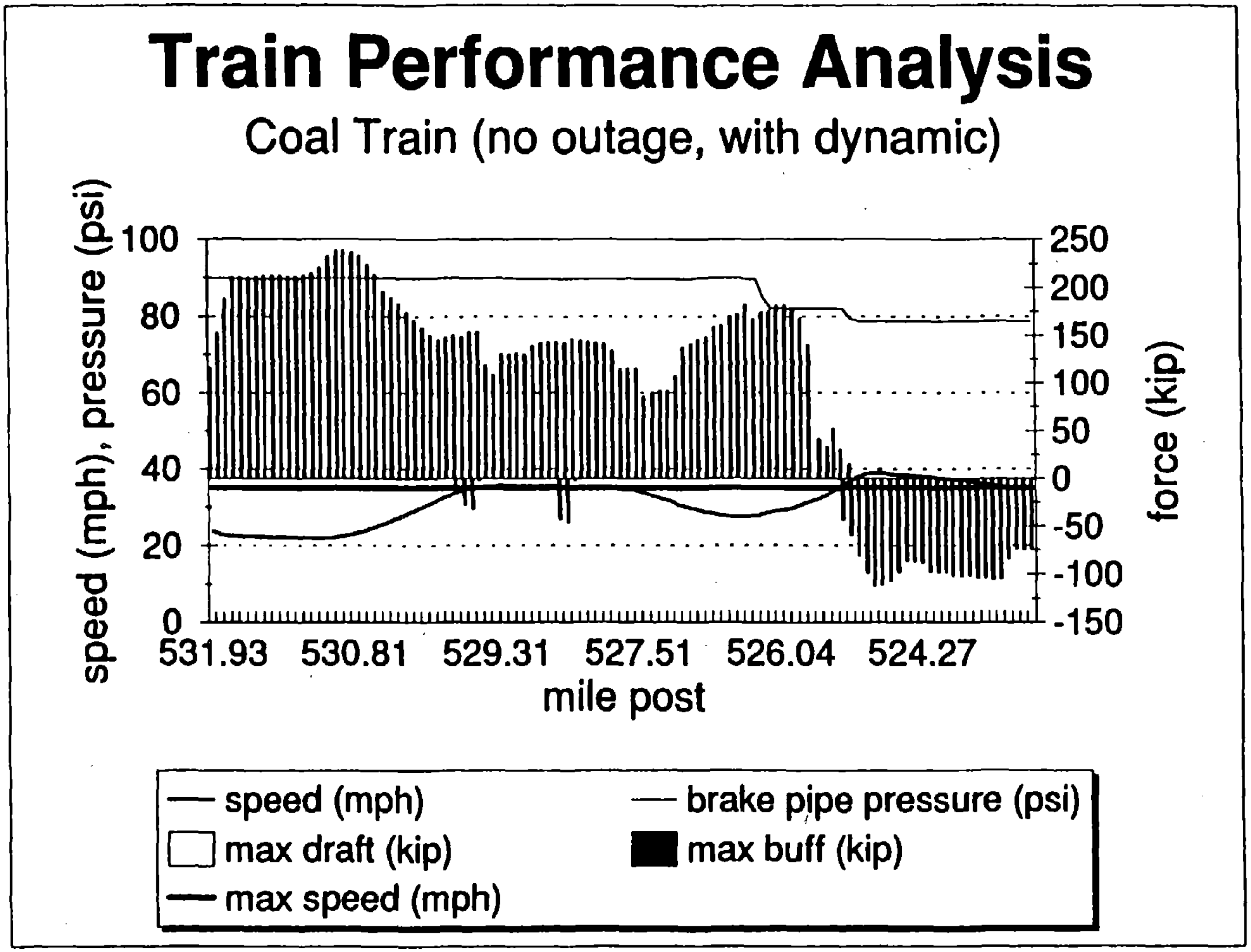

Figure B-5. Results for a Coal Train Dynamic Braking Operation with No Brake Outage

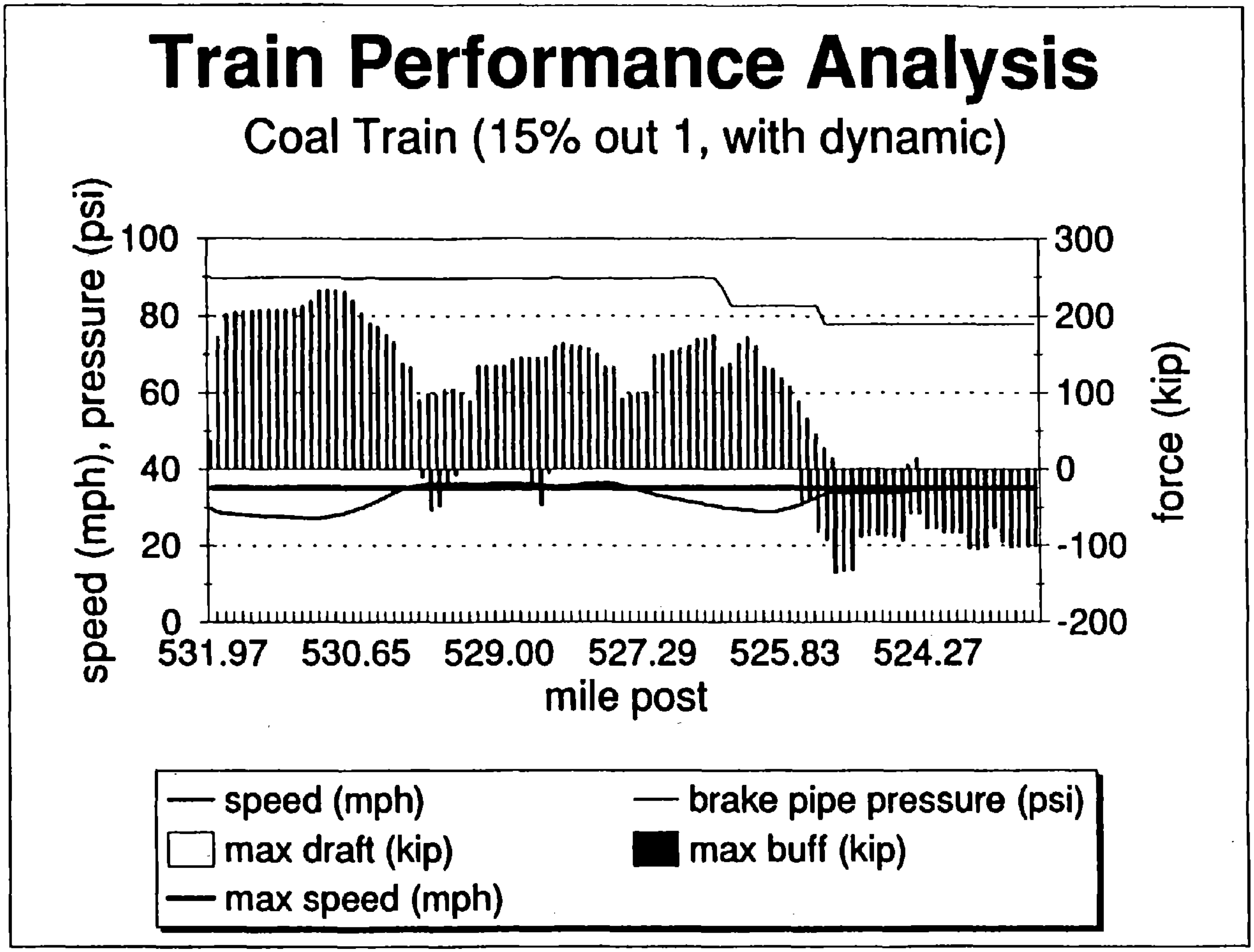

Figure B-6. Results for a Coal Train Dynamic Braking Operation with #1 at 15% Brake Outages

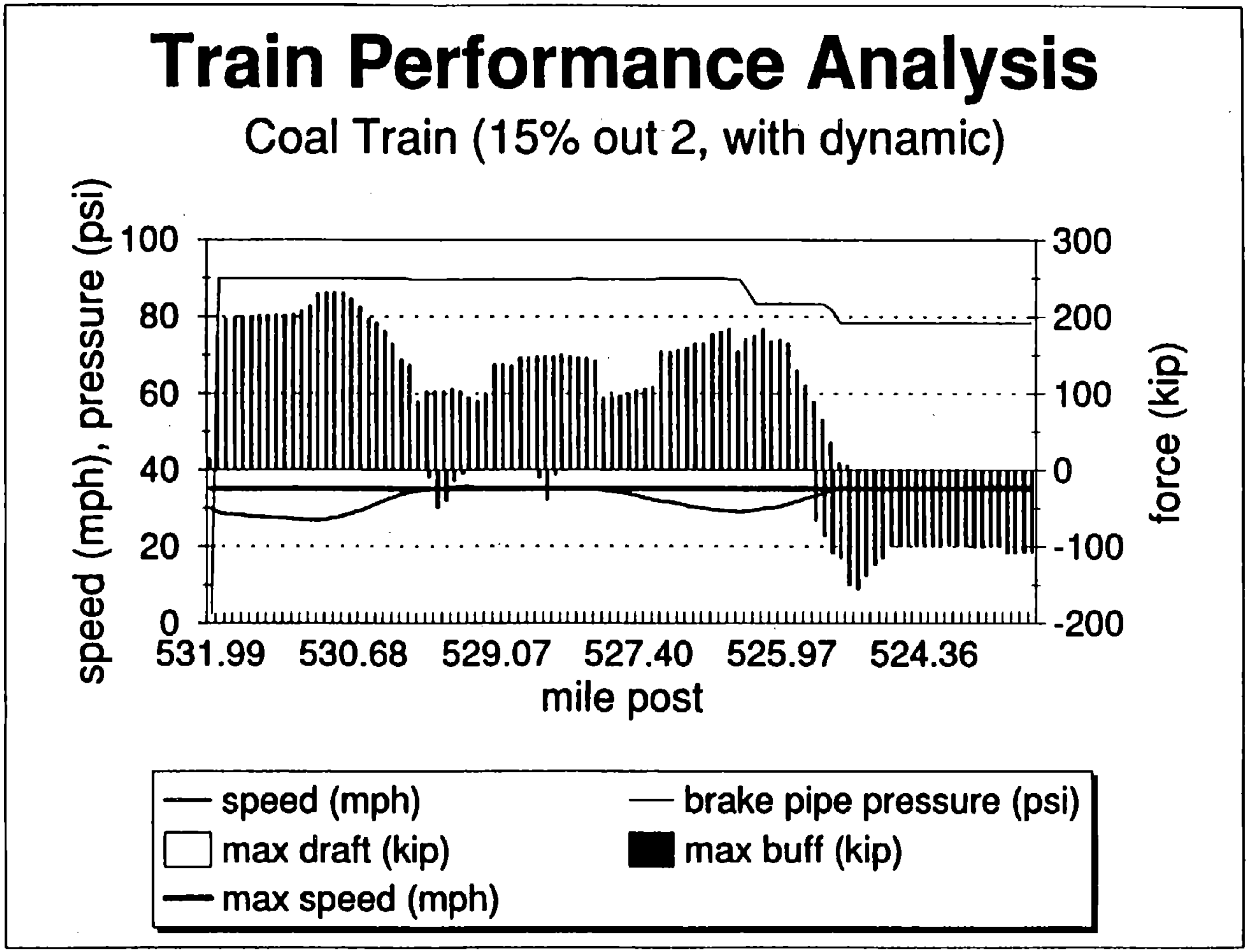

Figure B-7. Results for a Coal Train Dynamic Braking Operation with #2 at 15% Brake Outages

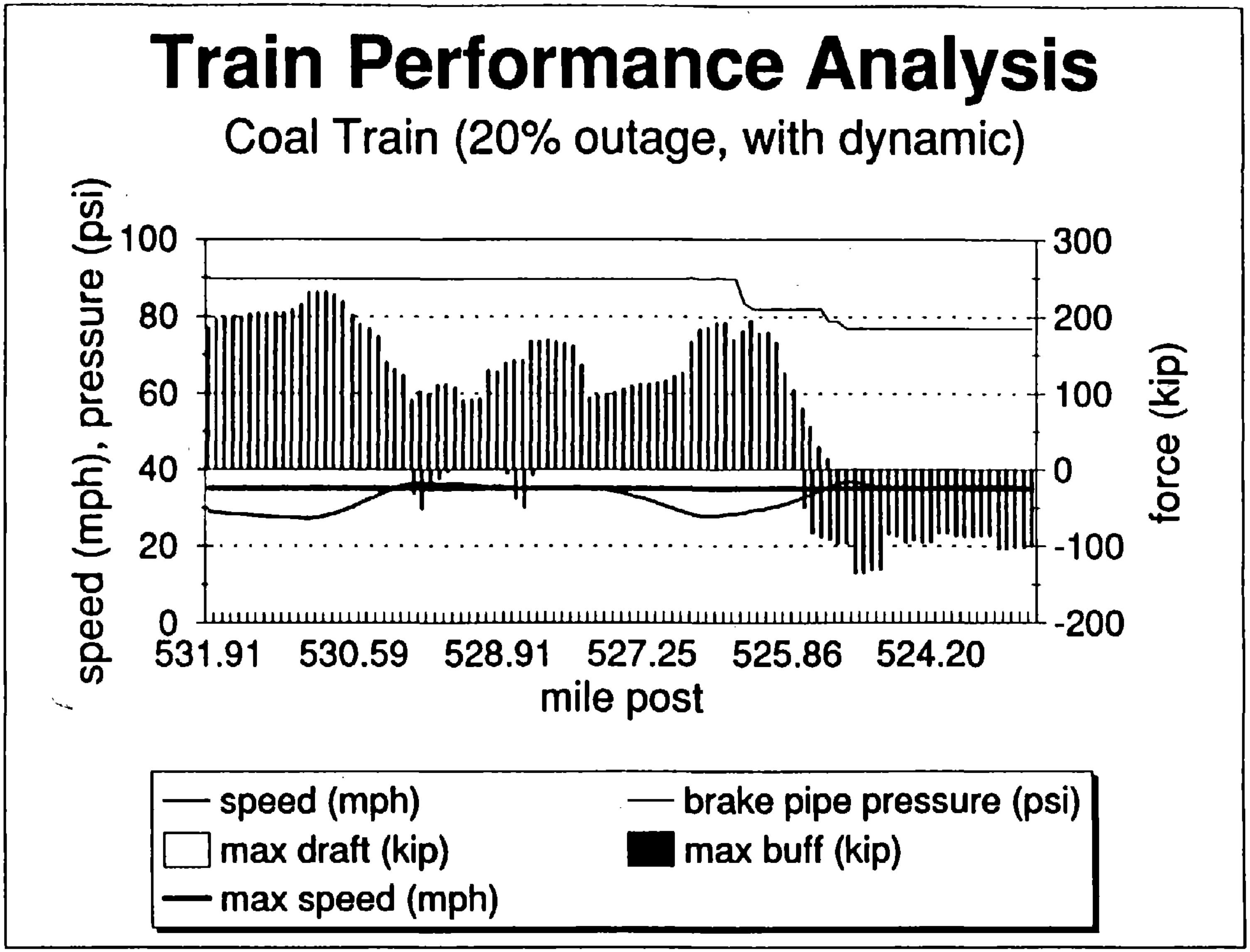

Figure B-8. Results for a Coal Train Dynamic Braking Operation with 20% Brake Outages

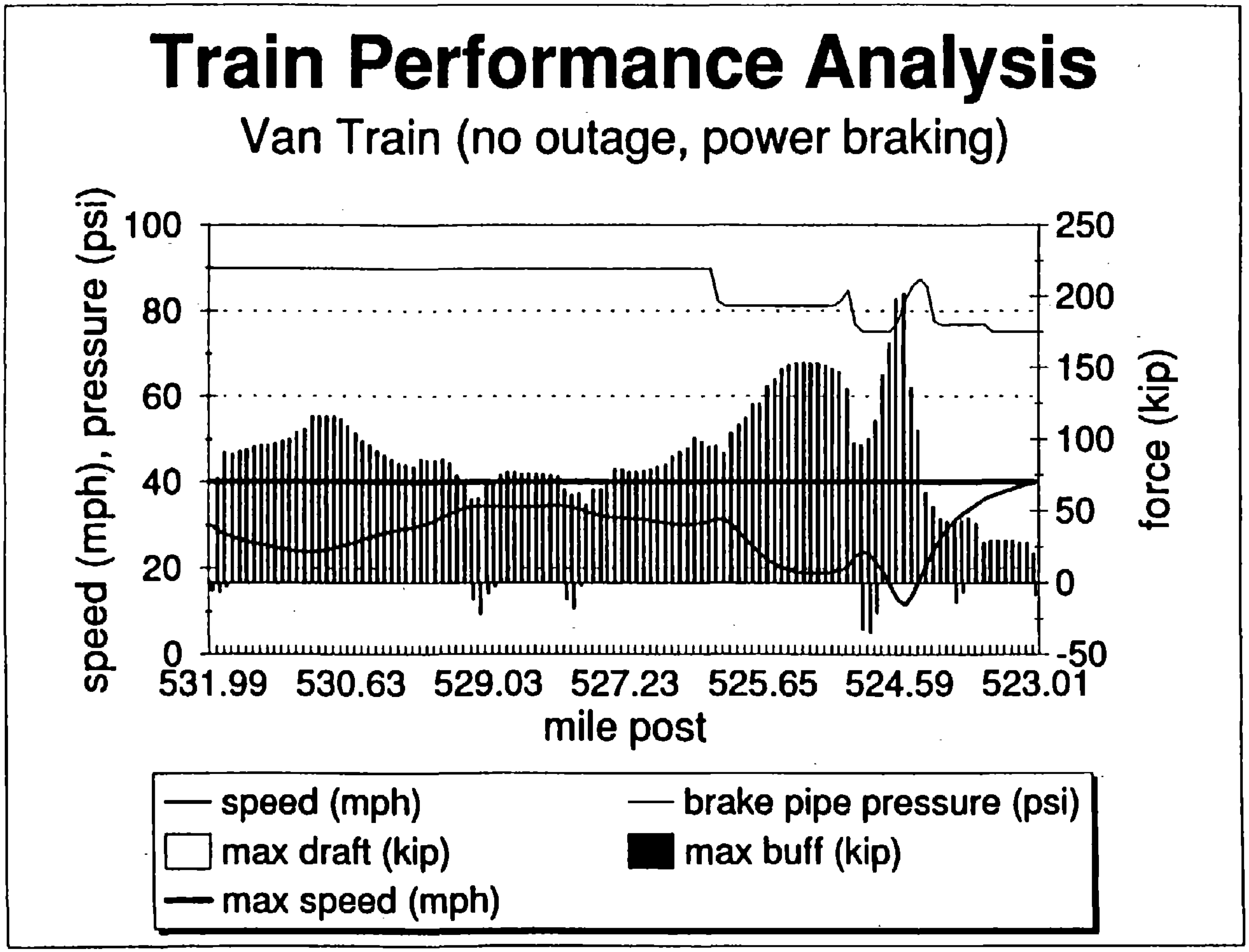

Figure B-9. Results for a Van Train Power Braking Operation with No Brake Outage

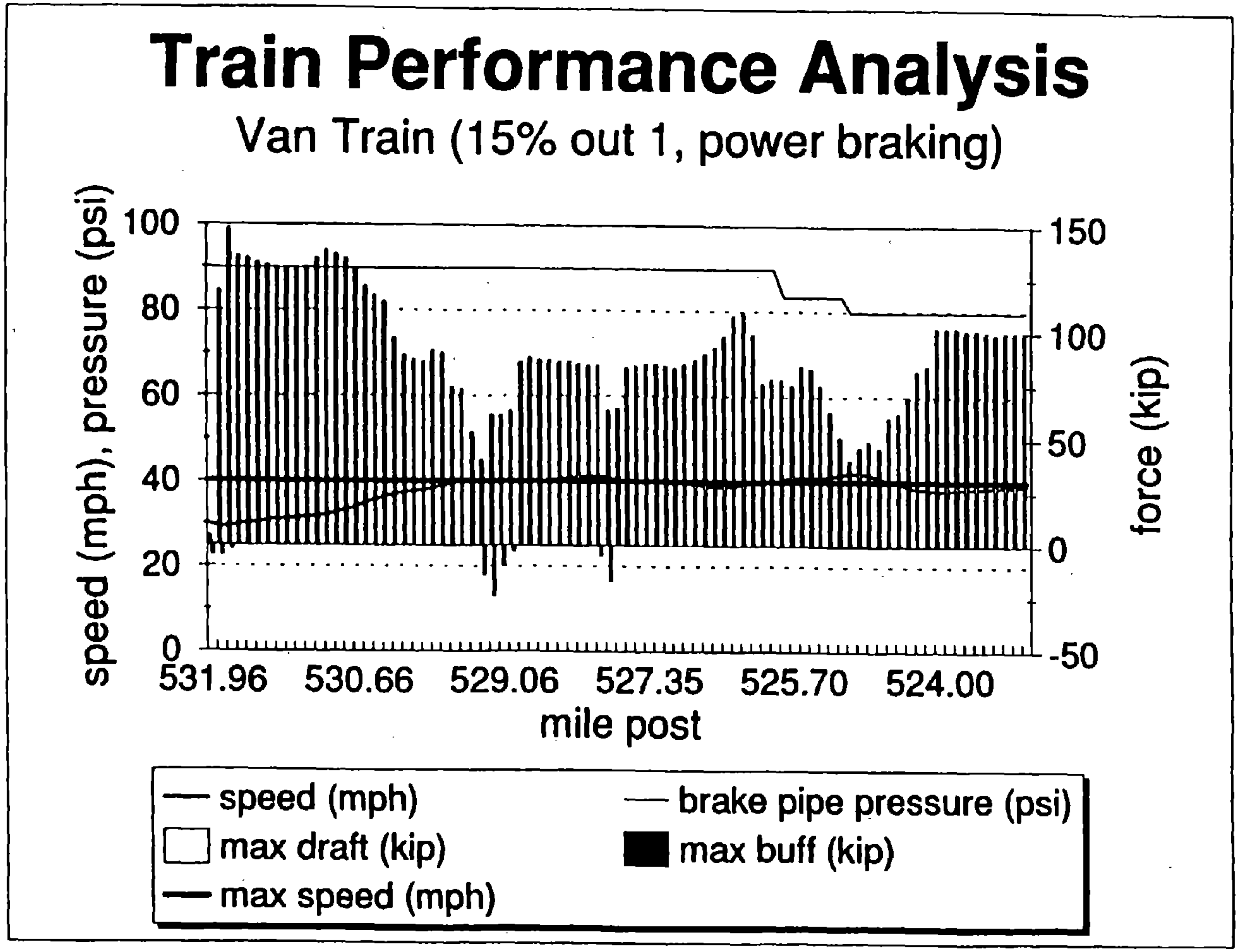

Figure B-10. Results for a Van Train Power Braking Operation with #1 at 15% Brake Outages

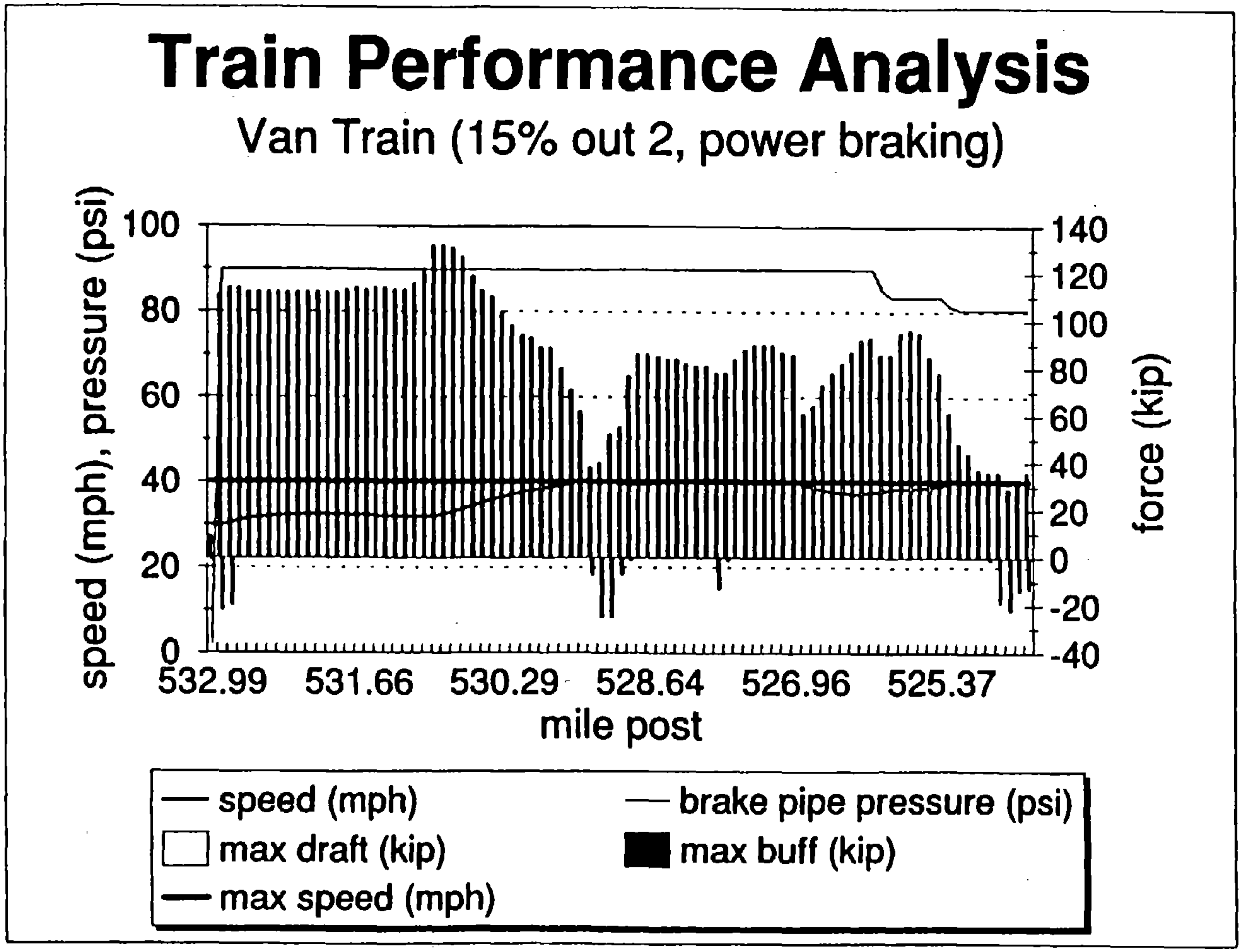

Figure B-11. Results for a Van Train Power Braking Operation with #2 at 15% Brake Outages

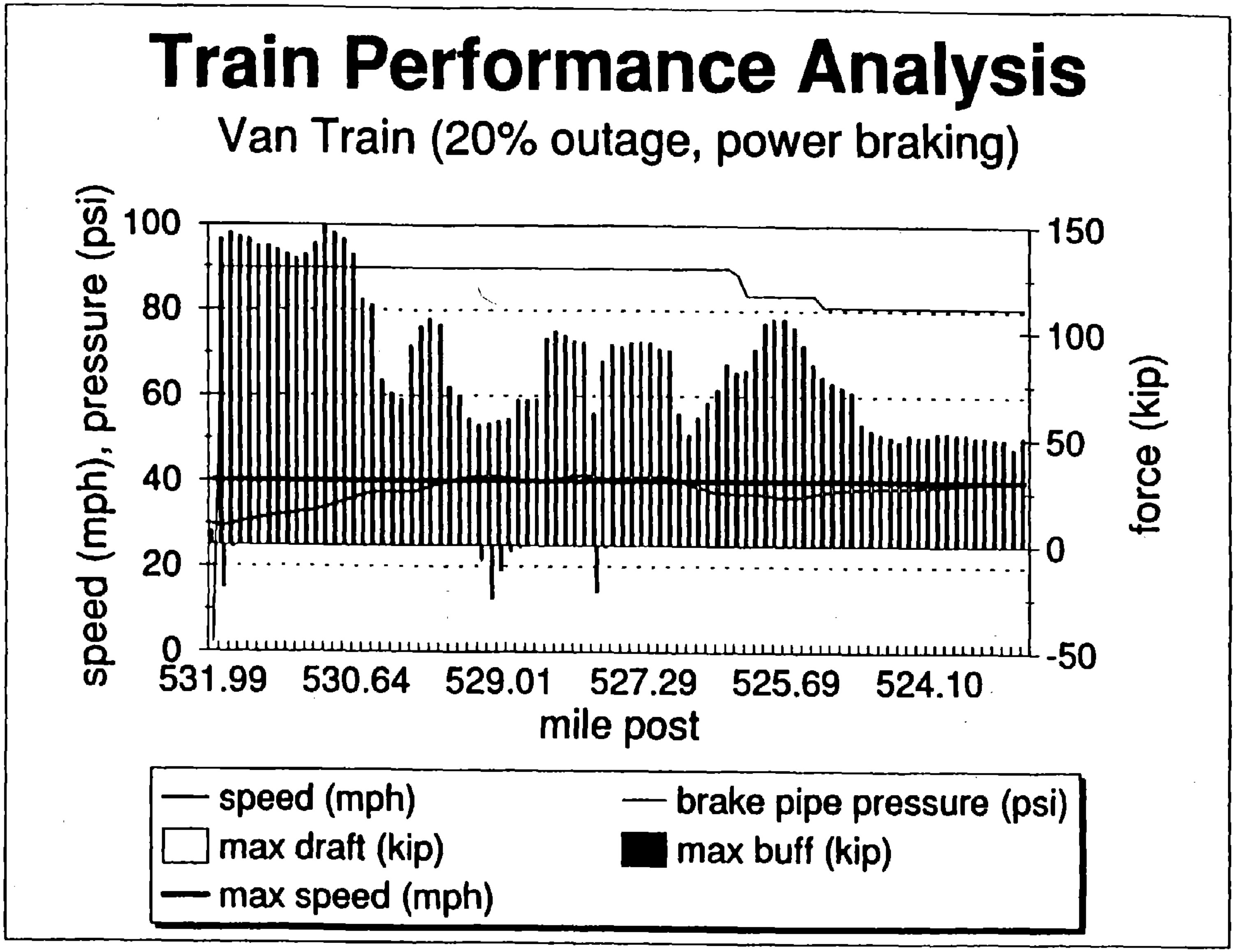

Figure B-12. Results for a Van Train Power Braking Operation with 20% Brake Outages

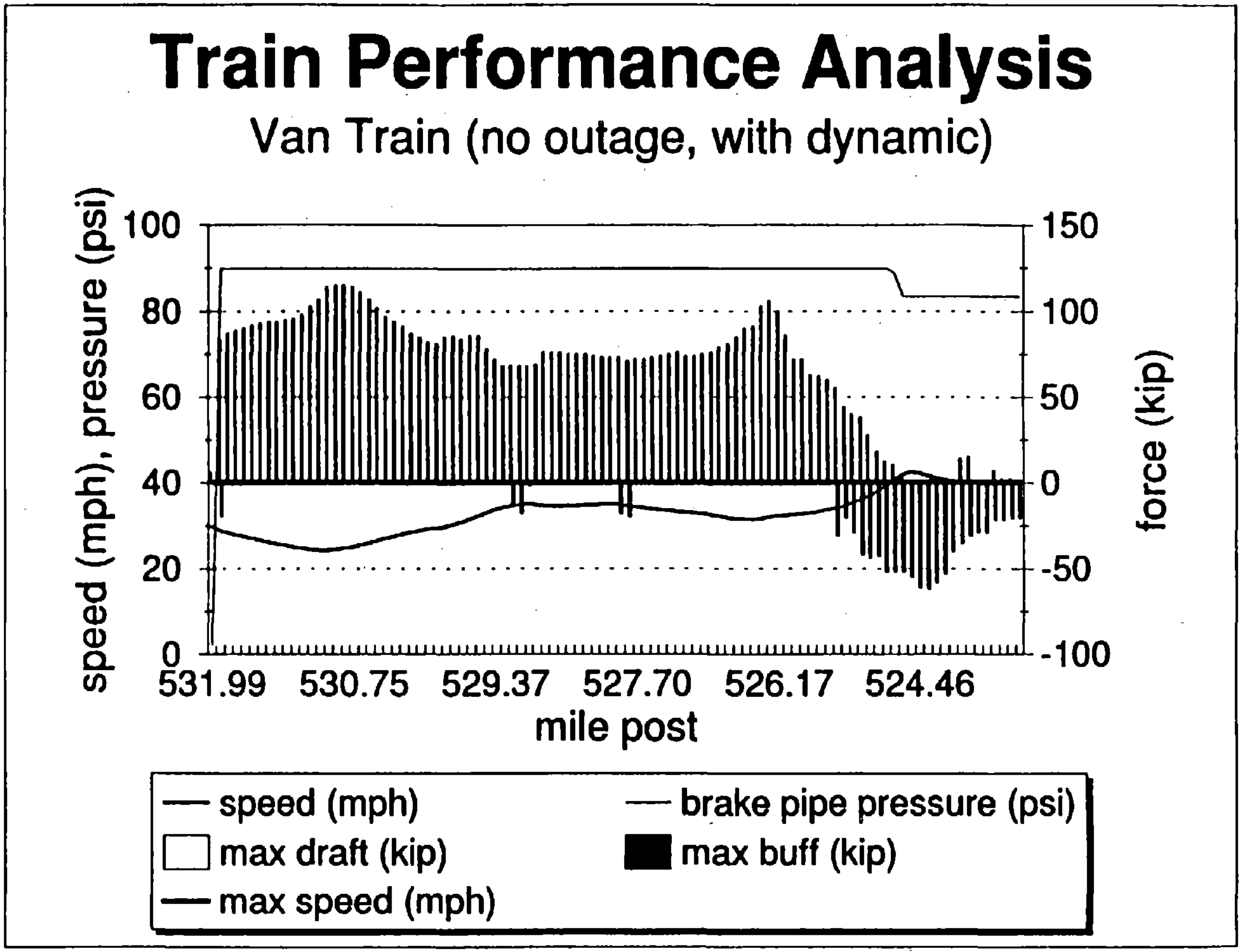

Figure B-13. Results for a Van Train Dynamic Braking Operation with No Brake Outage

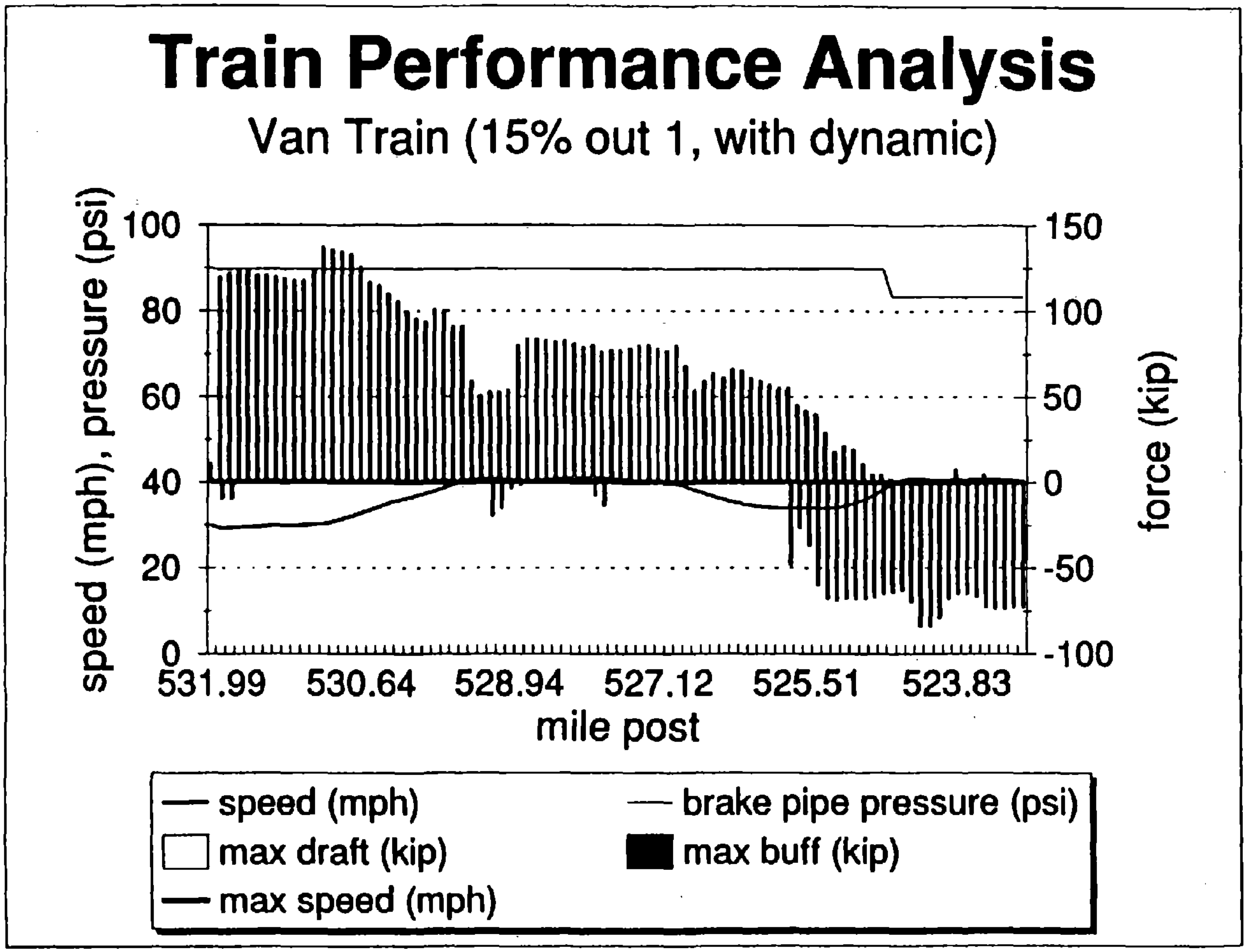

Figure B-14. Results for a Van Train Dynamic Braking Operation with #1 at 15% Brake Outages

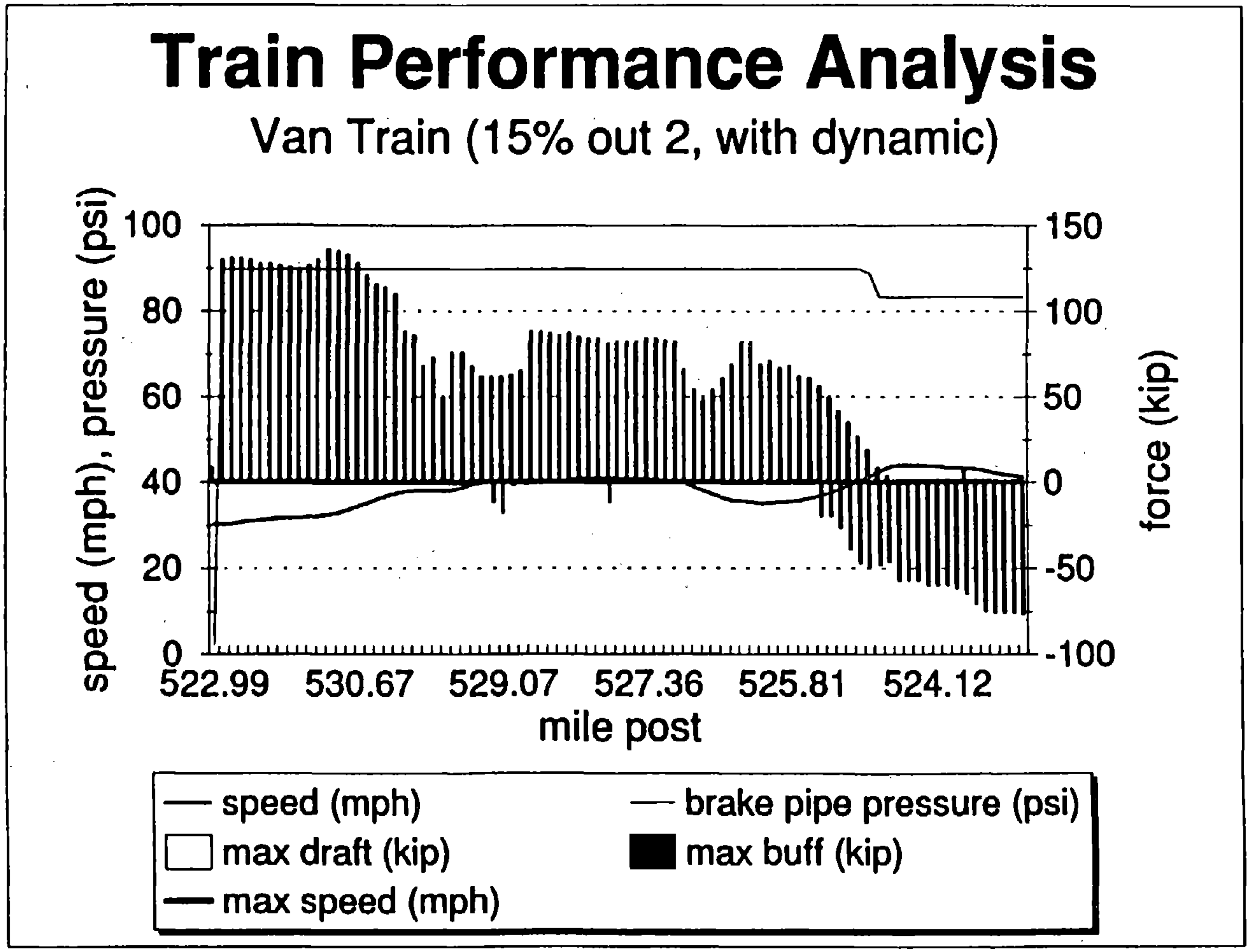

Figure B-15. Results for a Van Train Dynamic Braking Operation with #2 at 15% Brake Outages

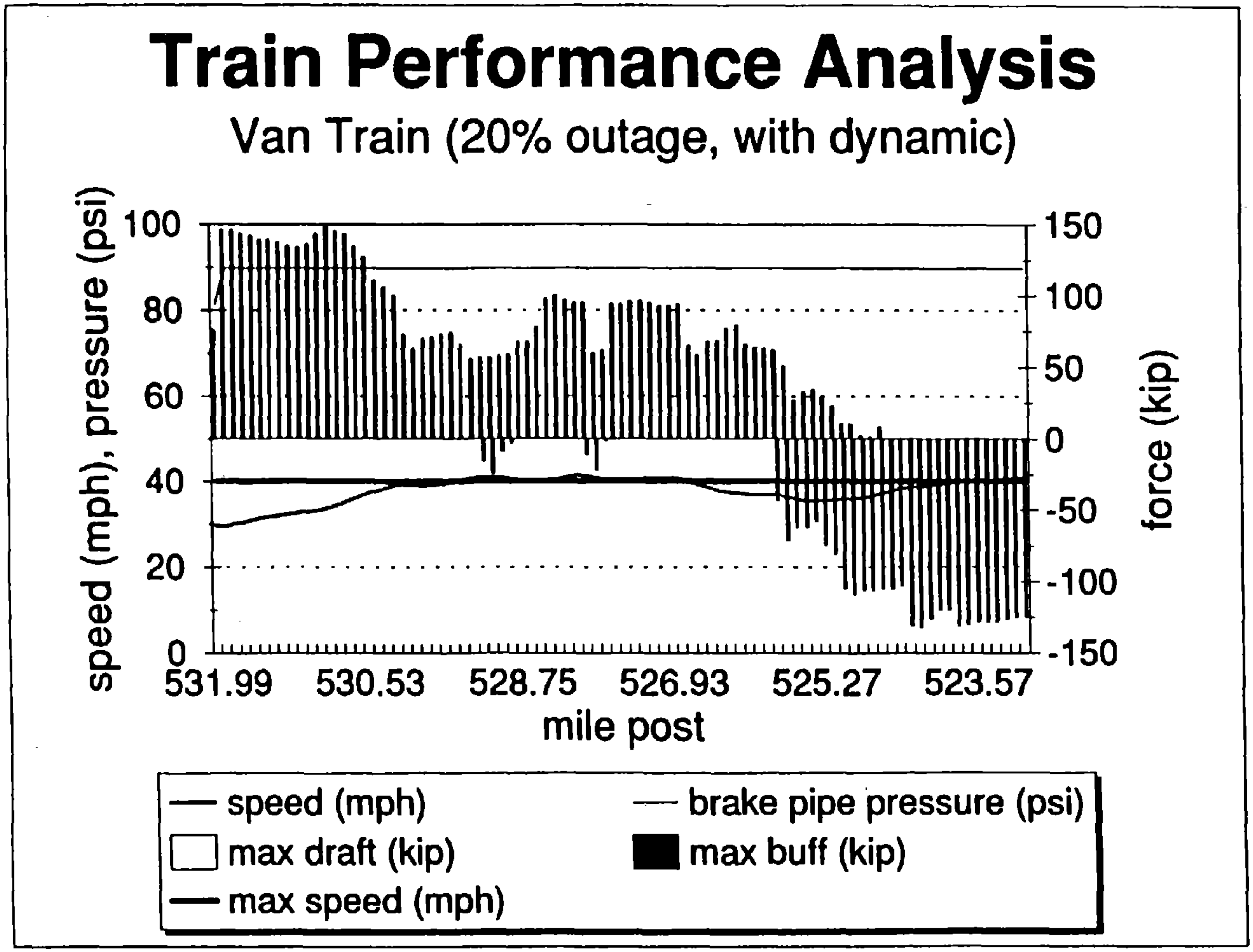

Figure B-16. Results for a Van Train Dynamic Braking Operation with 20% Brake Outages

Appendix C

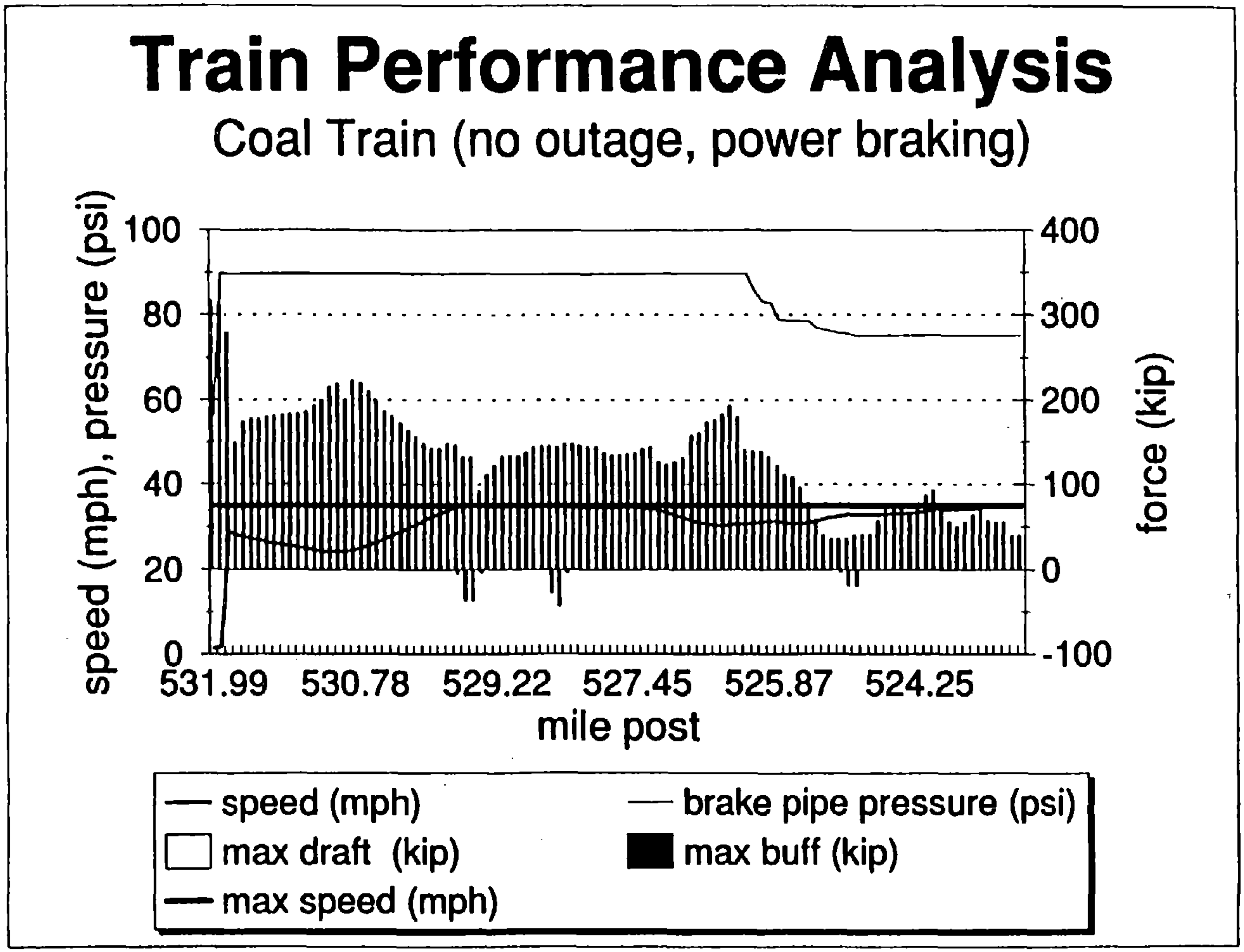

Figure C-1. Results for a Coal Train Power Braking Operation with No Brake Outage

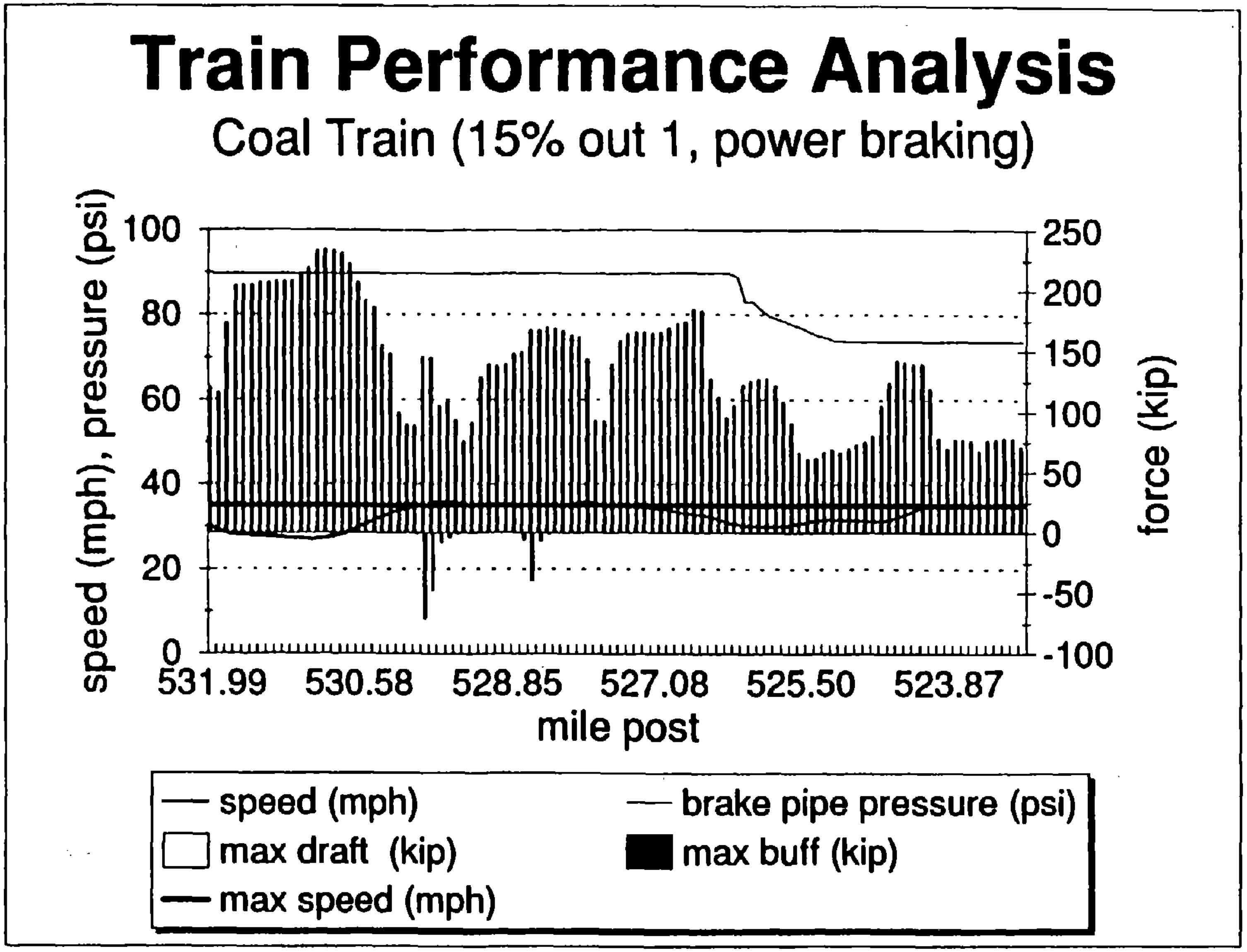

Figure C-2. Results for a Coal Train Power Braking Operation with #1 at 15% Brake Outages

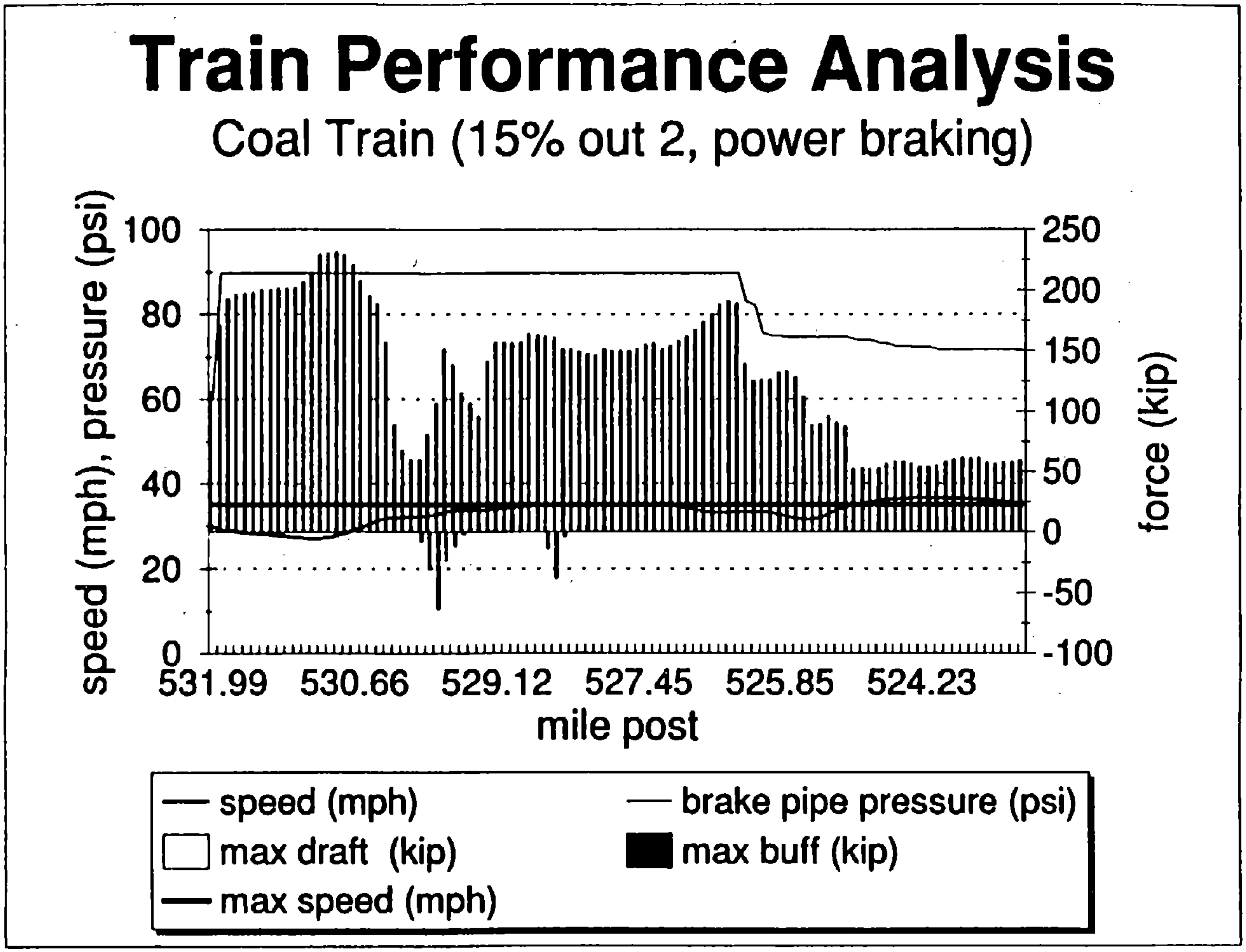

Figure C-3. Results for a Coal Train Power Braking Operation with #2 at 15% Brake Outages

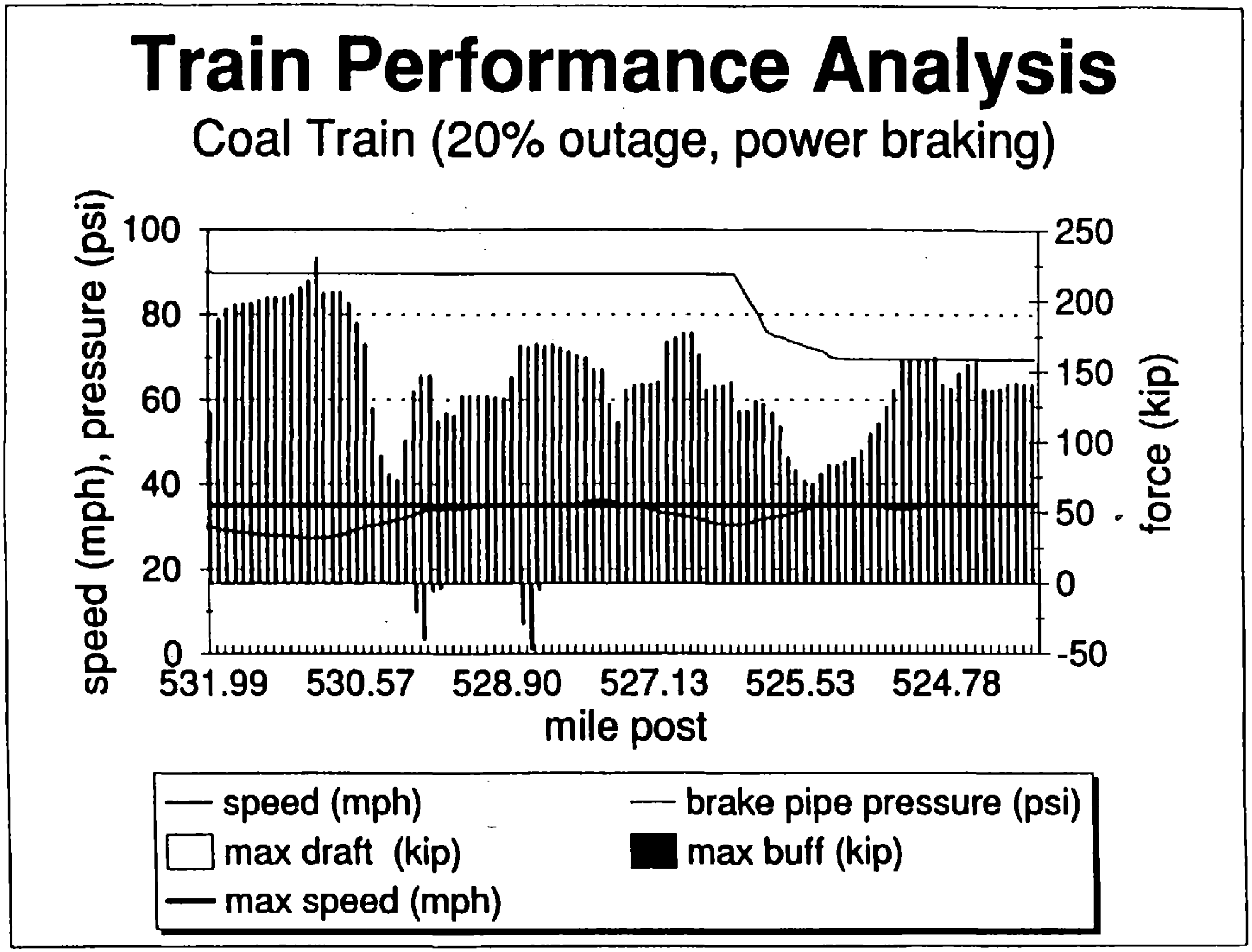

Figure C-4. Results for a Coal Train Power Braking Operation with 20% Brake Outages

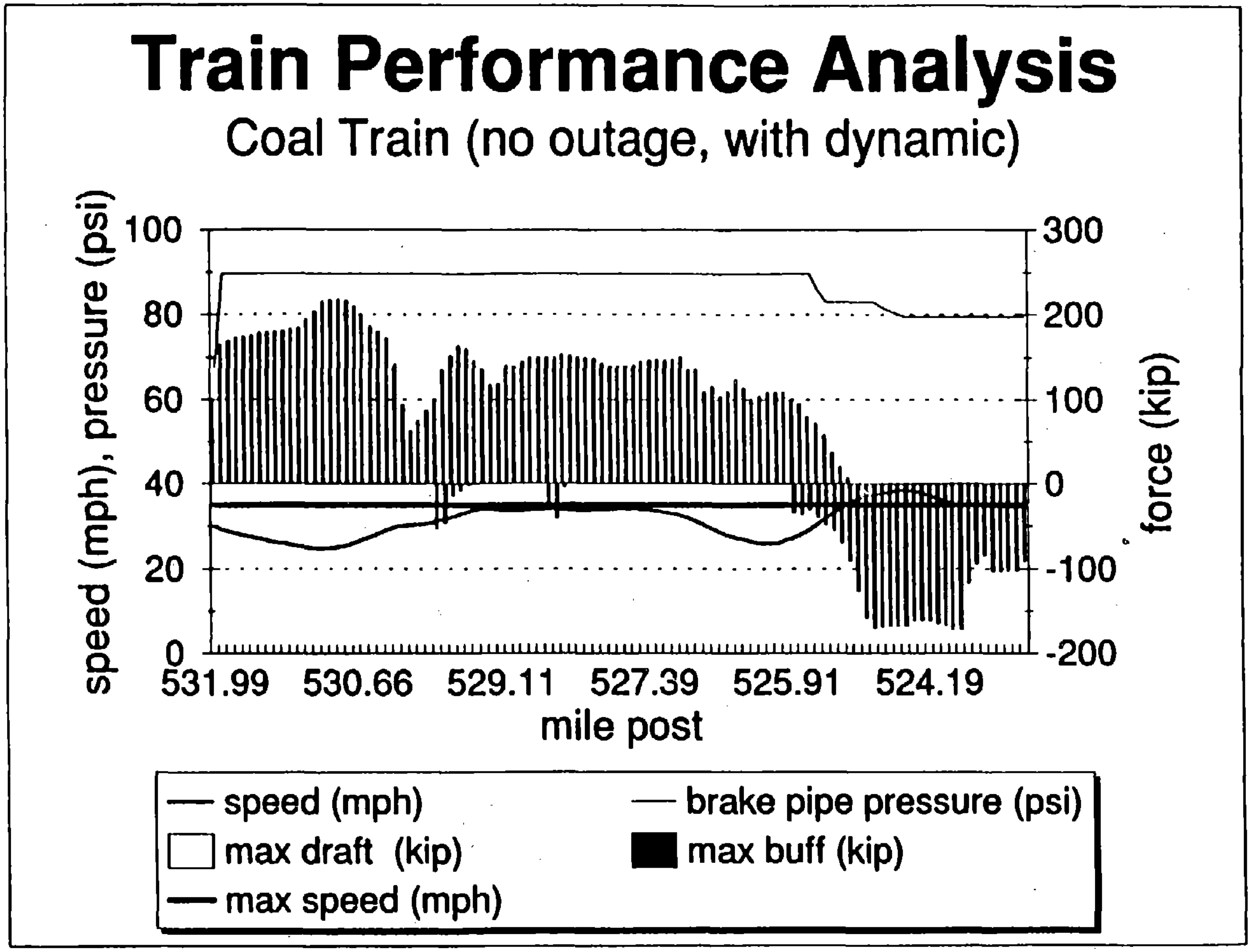

Figure C-5. Results for a Coal Train Dynamic Braking Operation with No Brake Outage

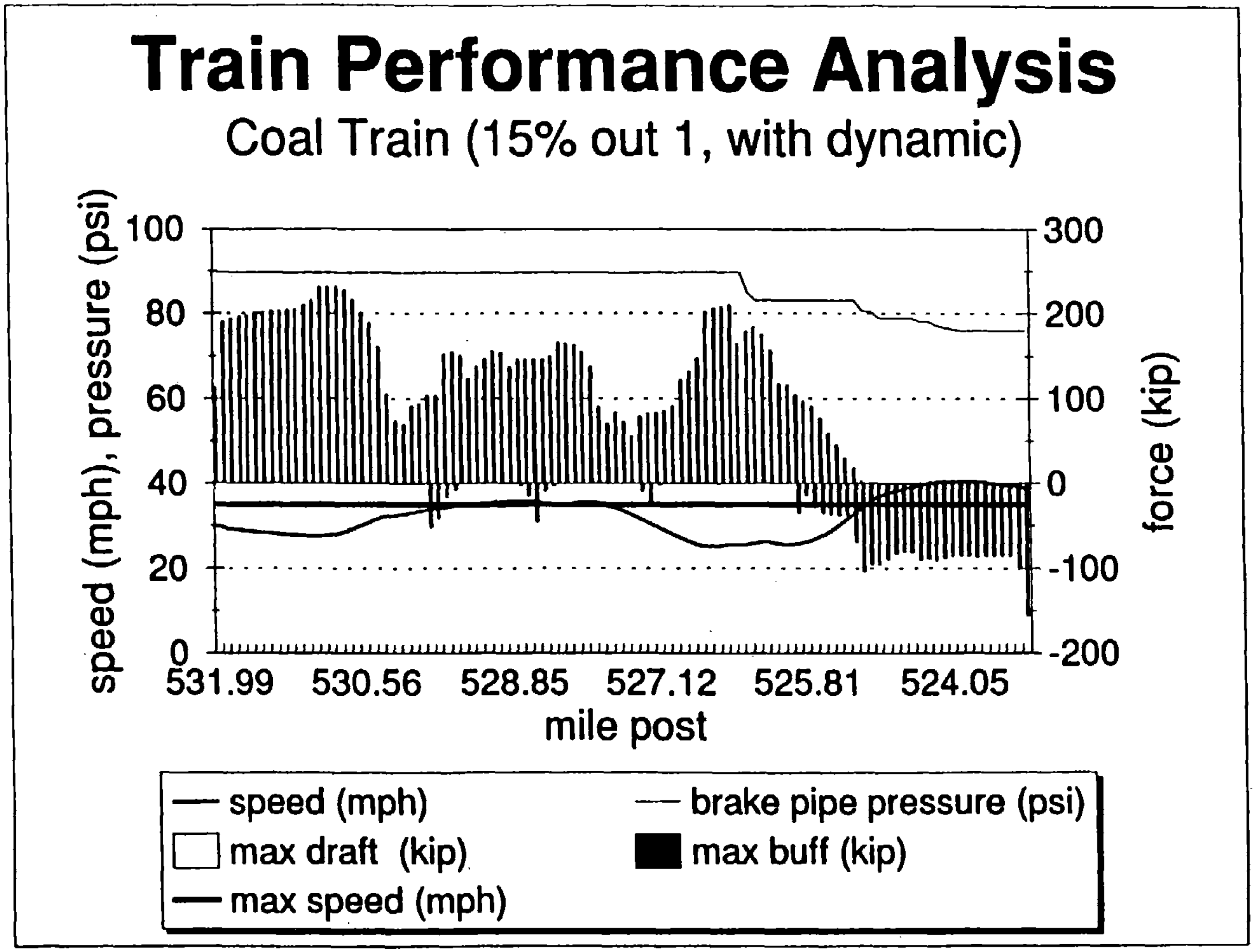

Figure C-6. Results for a Coal Train Dynamic Braking Operation with #1 at 15% Brake Outages

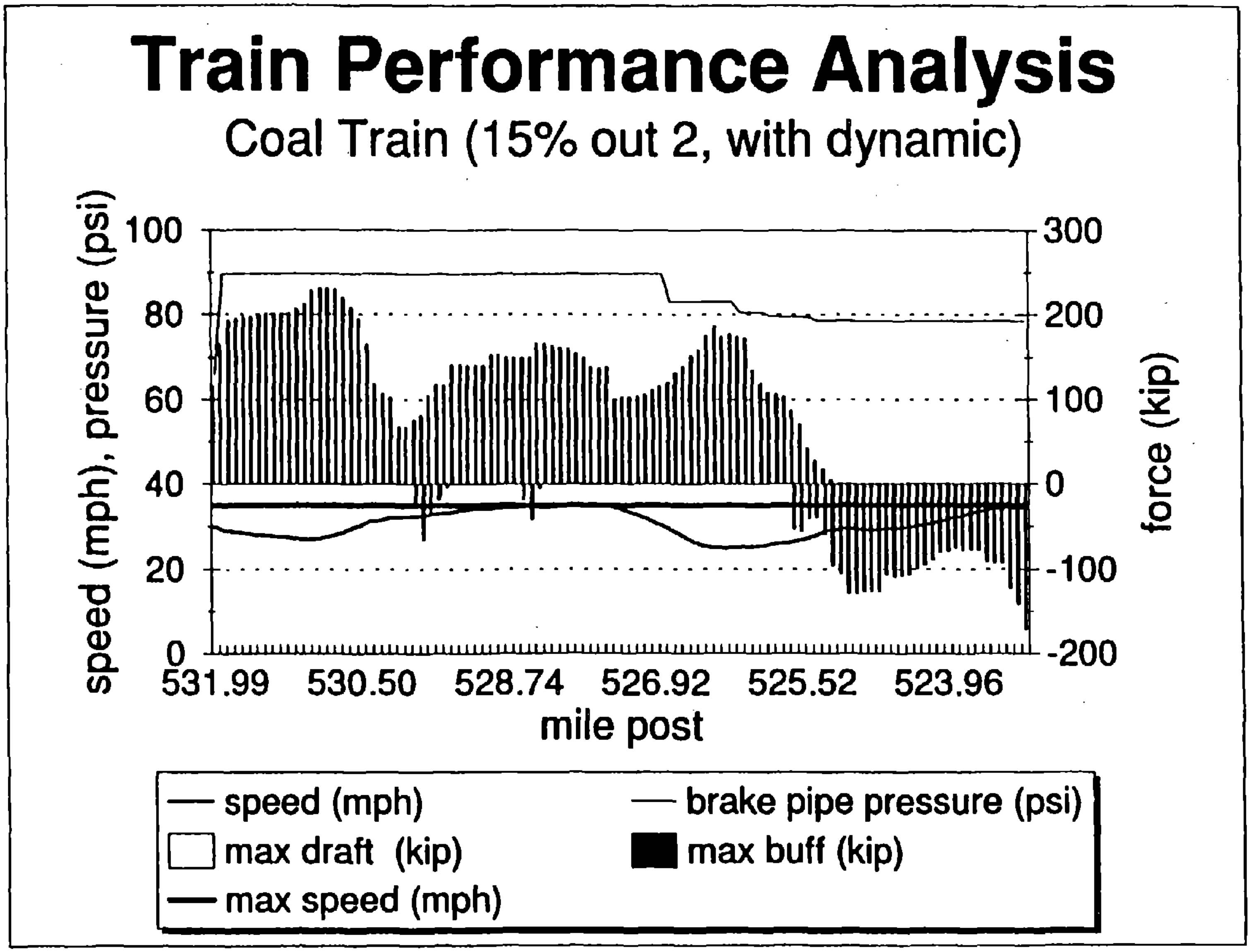

Figure C-7. Results for a Coal Train Dynamic Braking Operation with #2 at 15% Brake Outages

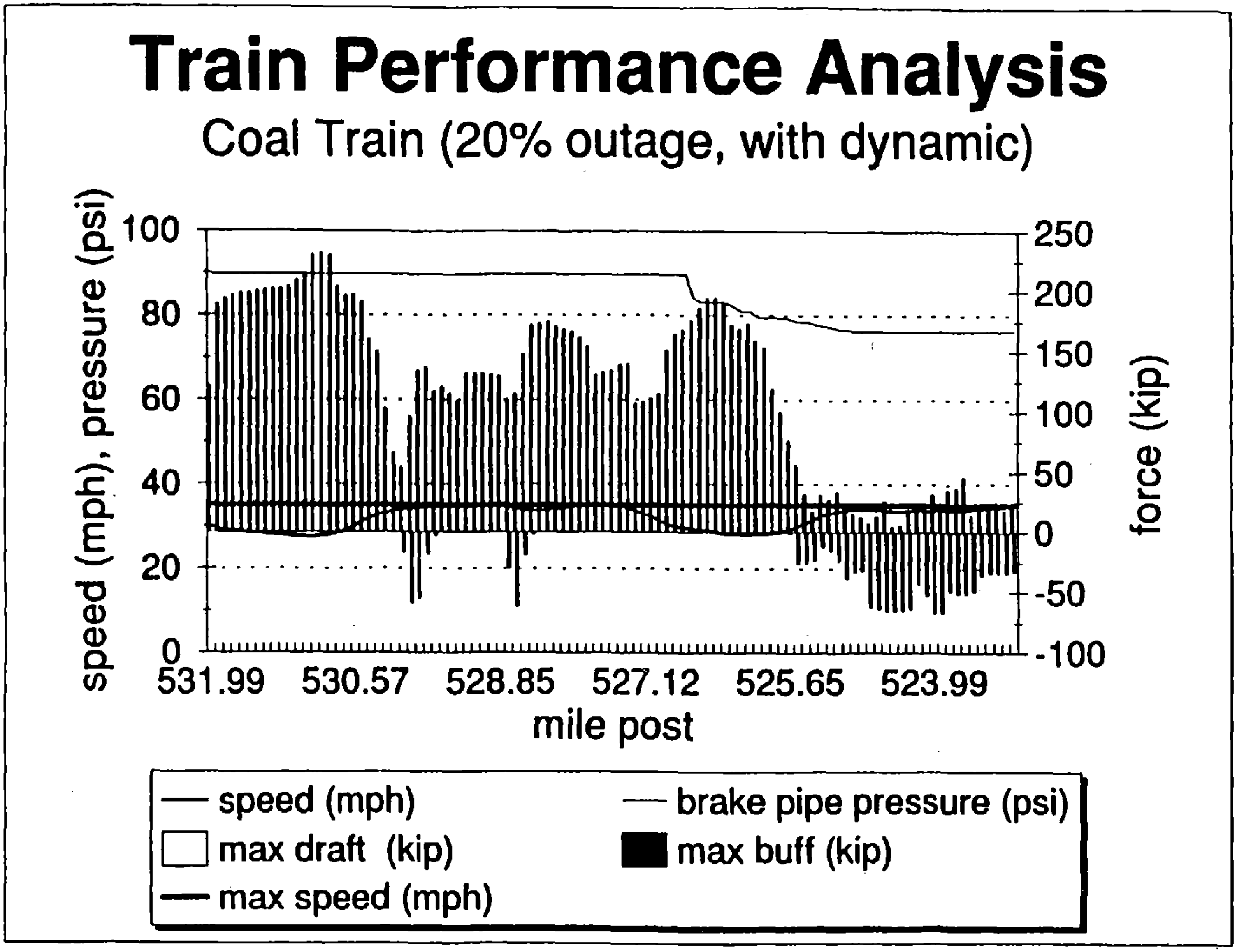

Figure C-8. Results for a Coal Train Dynamic Braking Operation with 20% Brake Outages

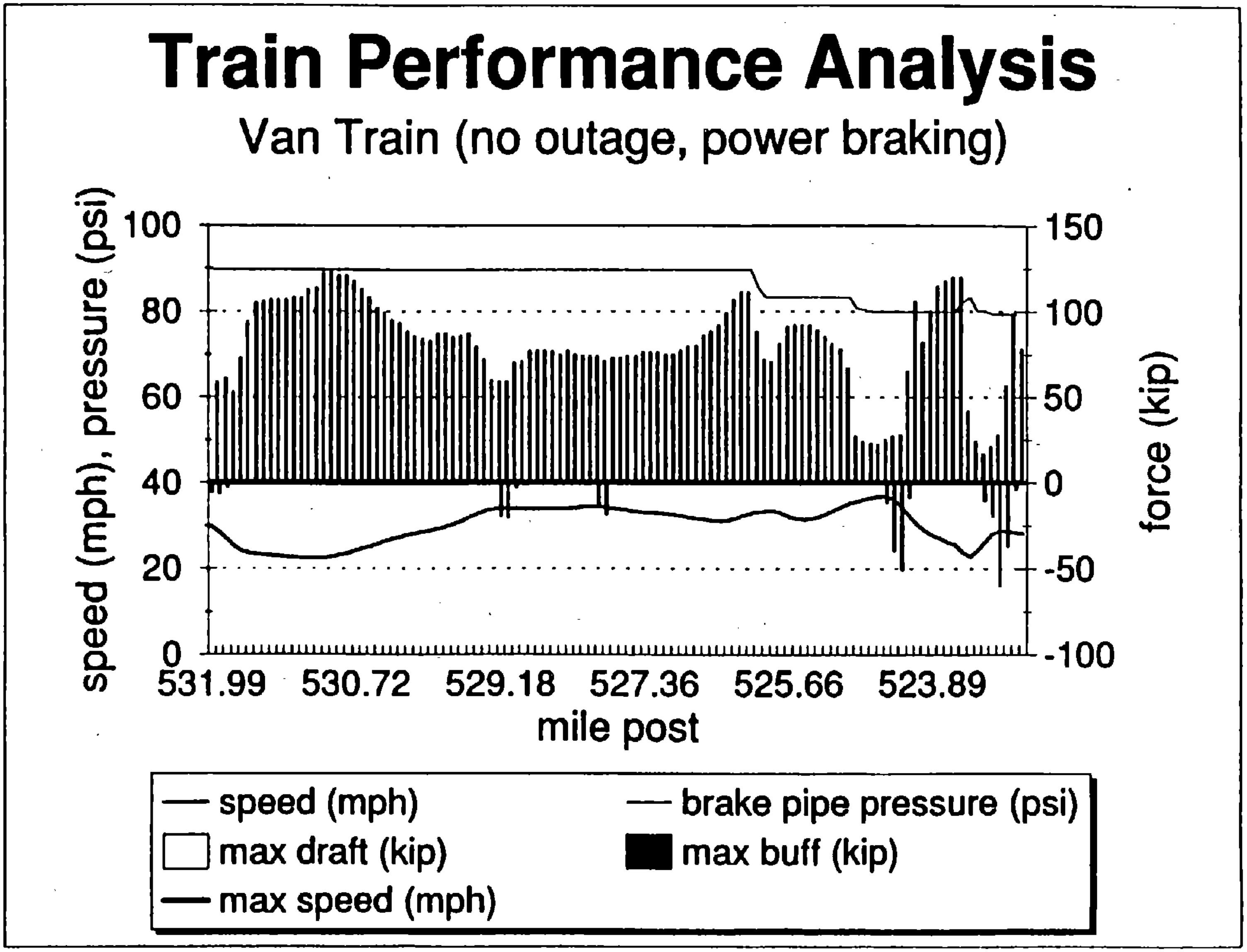

Figure C-9. Results for a Van Train Power Braking Operation with No Brake Outage

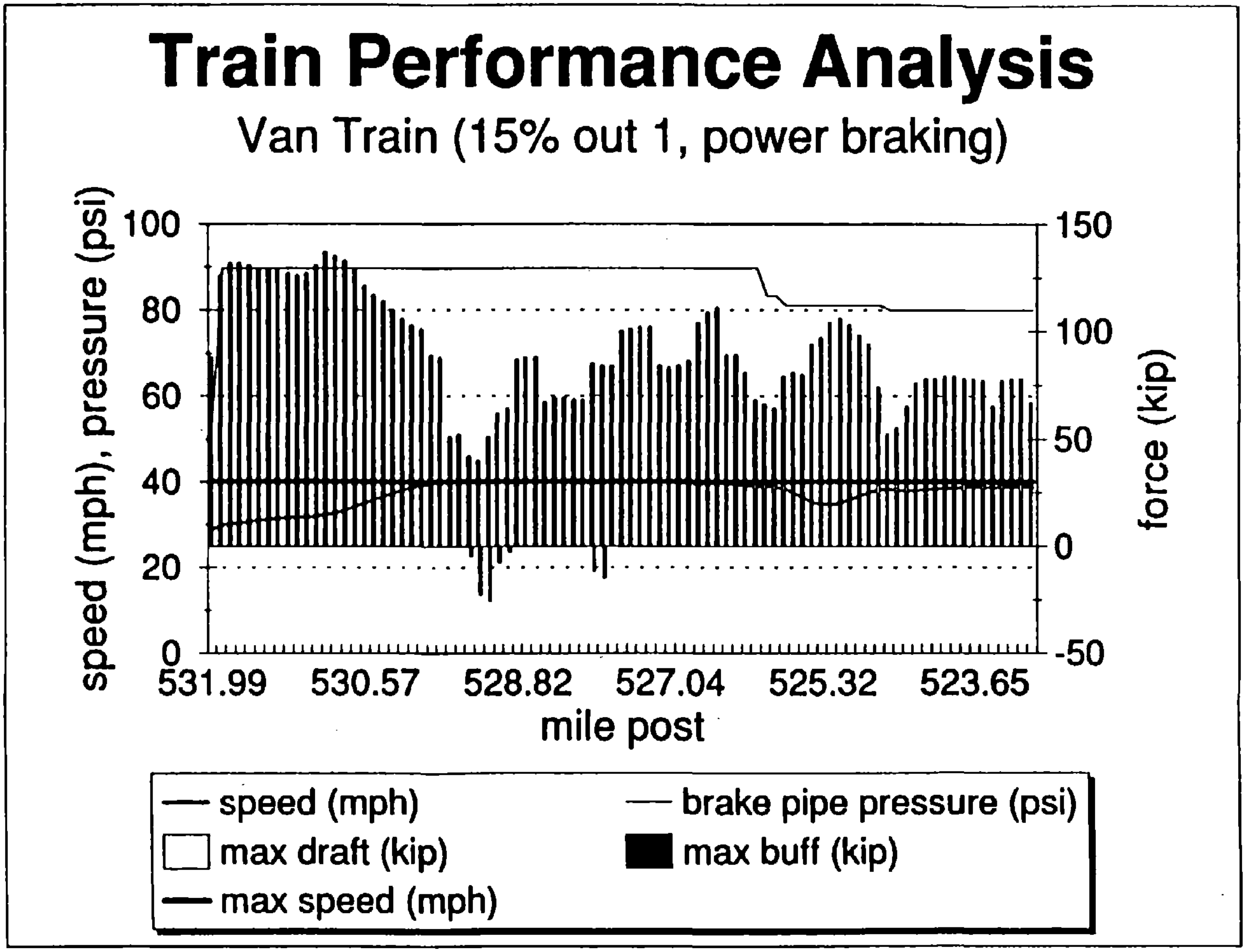

Figure C-10. Results for a Van Train Power Braking Operation with #1 at 15% Brake Outages

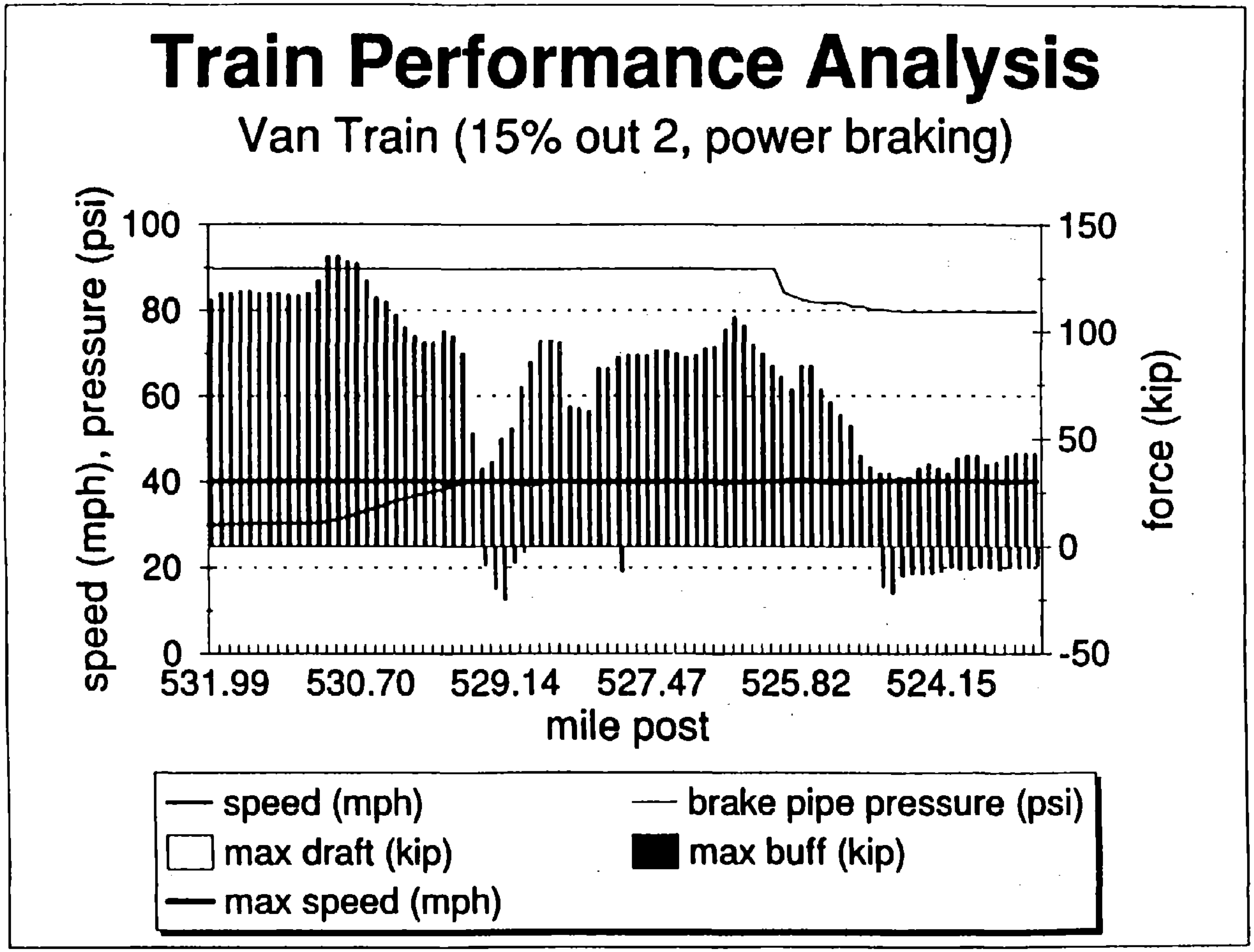

Figure C-11. Results for a Van Train Power Braking Operation with #2 at 15% Brake Outages

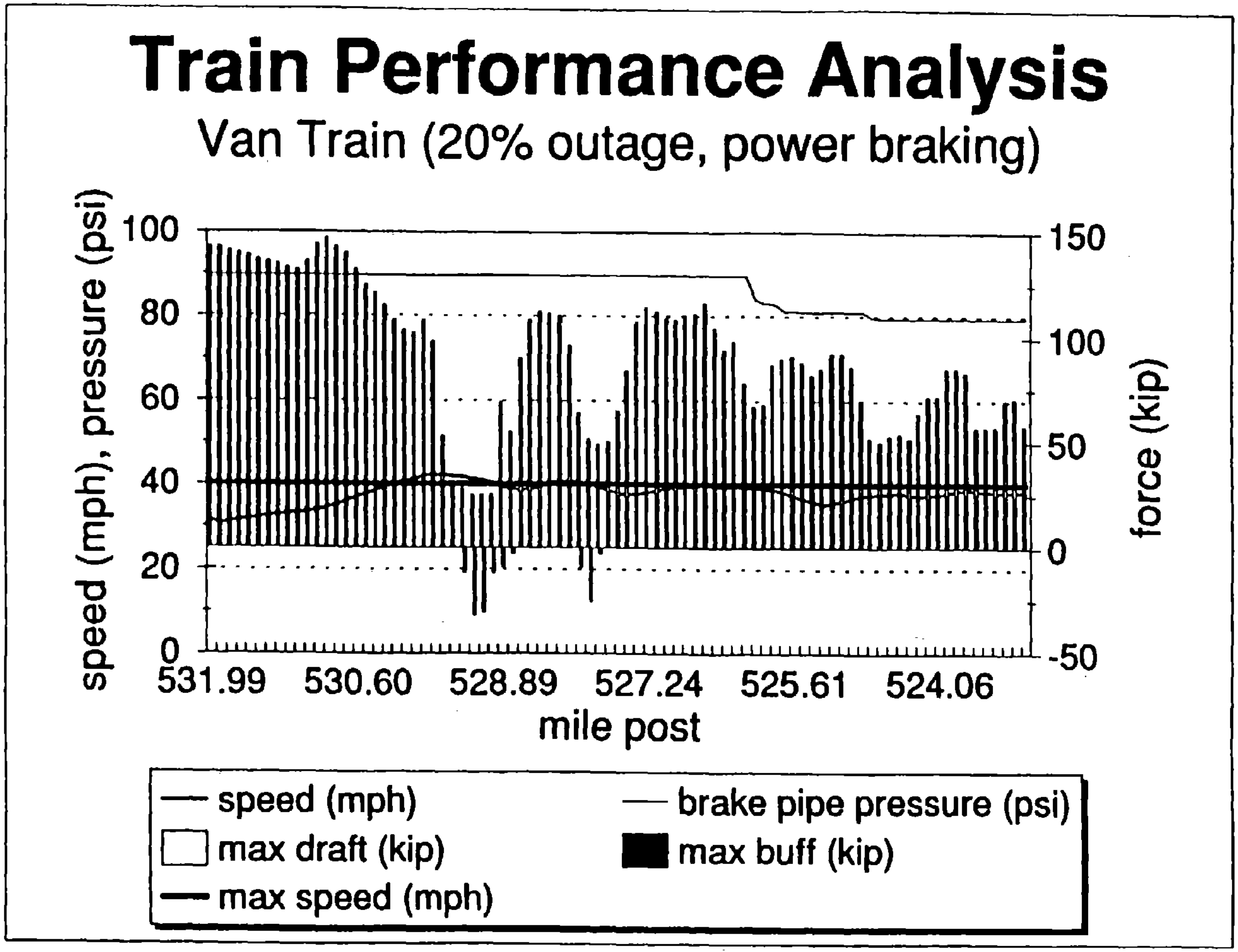

Figure C-12. Results for a Van Train Power Braking Operation with 20% Brake Outages

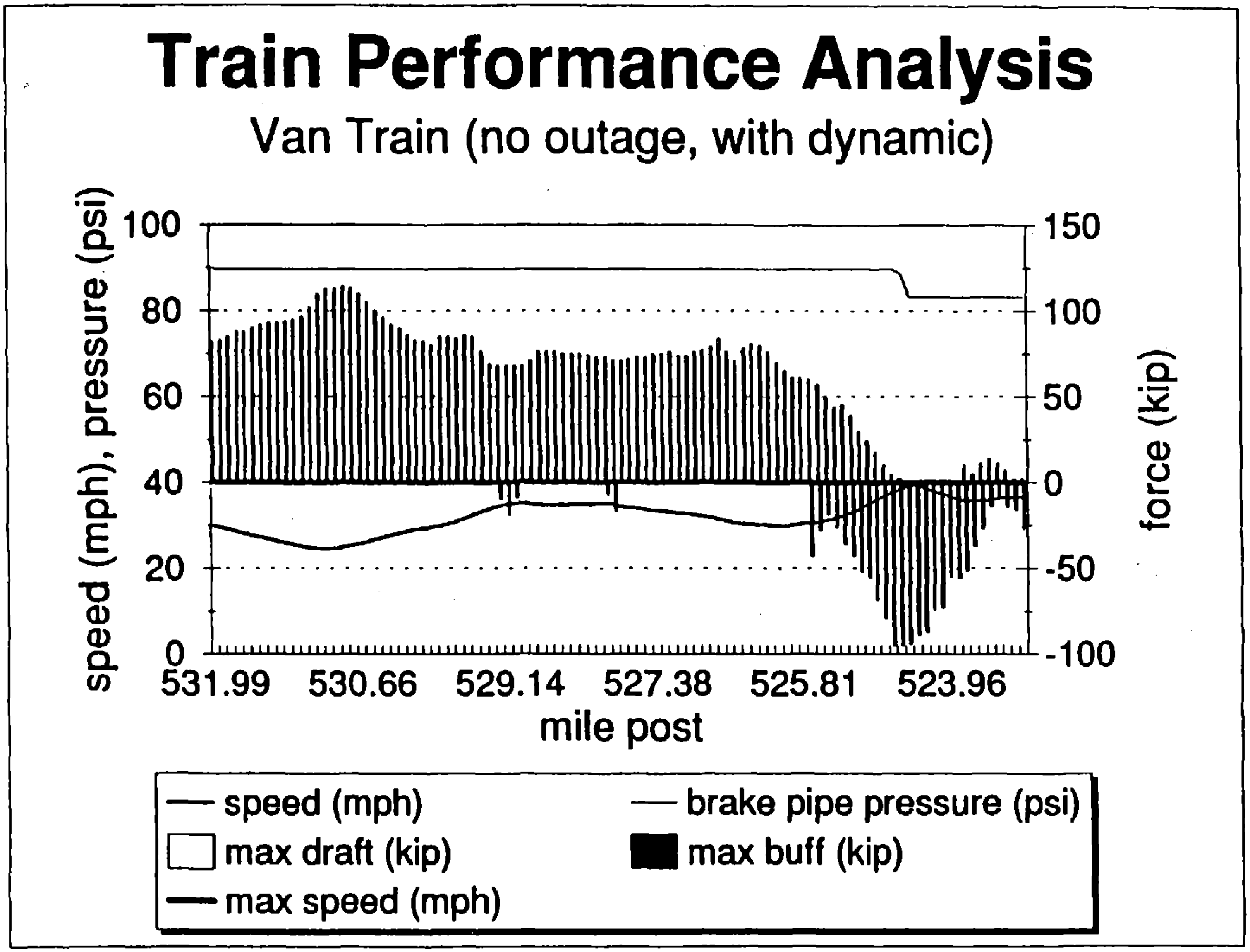

Figure C-13. Results for a Van Train Dynamic Braking Operation with No Brake Outage

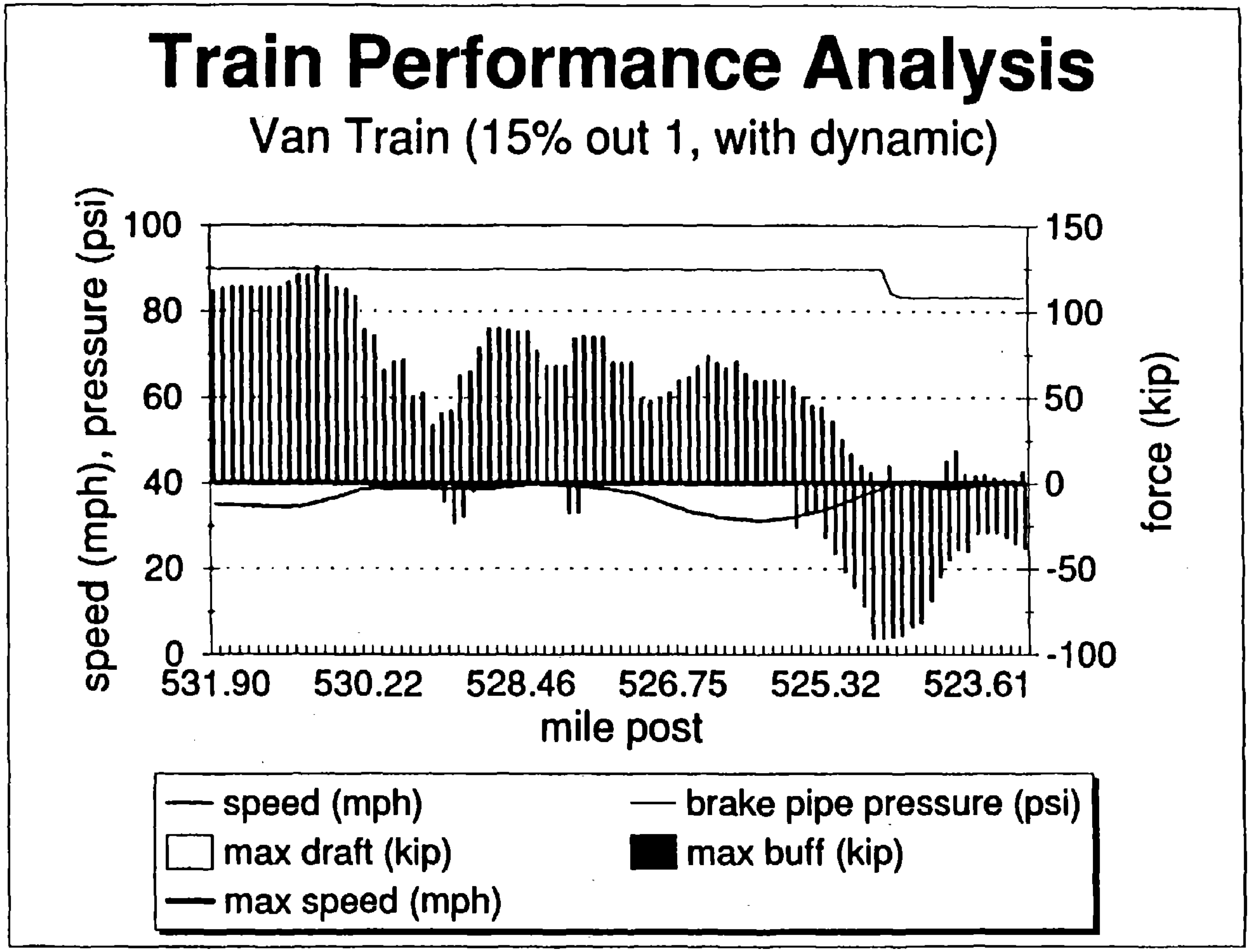

Figure C-14. Results for a Van Train Dynamic Braking Operation with #1 at 15% Brake Outages

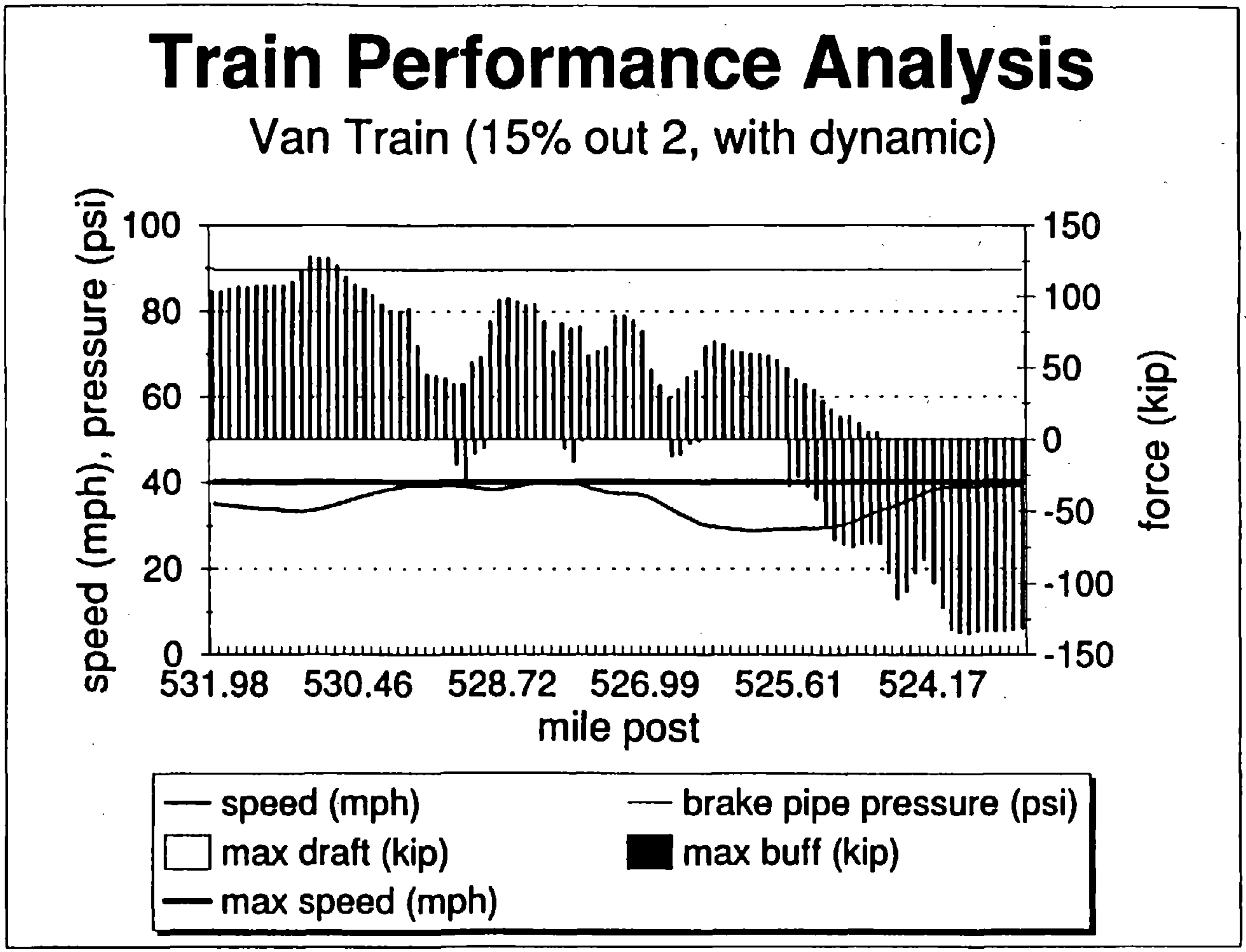

Figure C-15. Results for a Van Train Dynamic Braking Operation with #2 at 15% Brake Outages

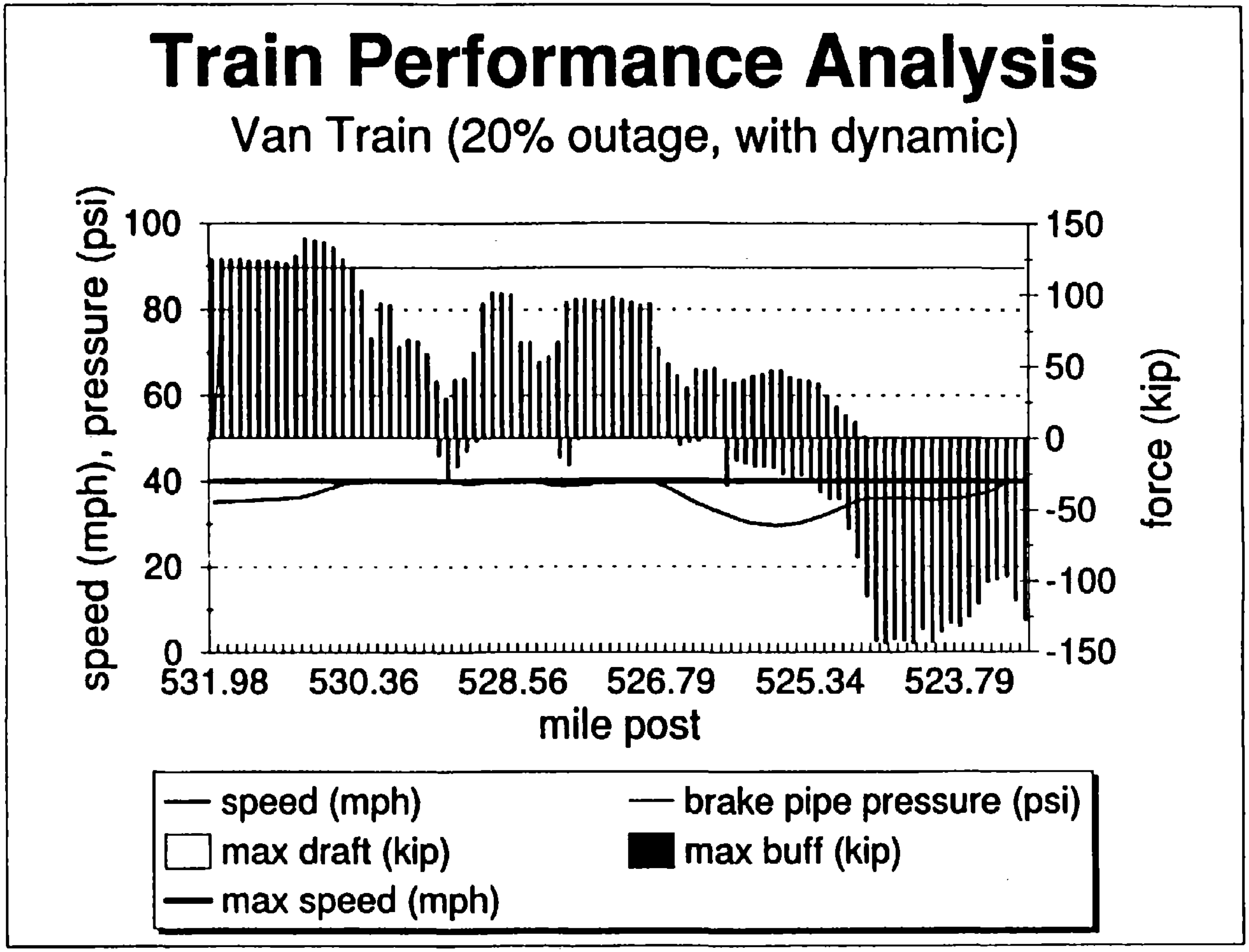

Figure C-16. Results for a Van Train Dynamic Braking Operation with 20% Brake Outages