Effectiveness of Various Schemes in Controlling the Behavior of Continuous Welded Rail

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The effectiveness of the various schemes railroads have used to control the behavior of continuous welded rail (CWR) over the past 15 years is discussed in this paper. Considerations and procedures used in the investigation of train derailments in which track buckling may be a causal factor are addressed, and 16 derailments are reviewed in detail. A pattern of several factors was found that either lowered the neutral rail temperature or materially reduced the lateral stability of the track. These factors were longitudinal rail creep, the chording inward of curves, addition of too much rail, and failure to sufficiently consolidate the ballast after it has been disturbed before trains pass at scheduled speeds. Rail creep may be reduced by adding more rail anchors or reducing train speeds and braking forces until the ballast has been compacted by trains or by mechanical methods. Reference staking under certain conditions will determine if curve chording has taken place and if adjustments will be necessary. After CWR is cut in cool weather, rail adjustments need to be made in order to avoid the addition of rail. After track is disturbed at high temperatures, the ballast must be adequately consolidated before trains are allowed to resume higher speeds. Railroads must have clear instructions on maintenance practices that could result in track buckling and train personnel to understand the application of these instructions.

Under the provisions of the Accident Reports Act (Title 45, U.S. Code), FRA has the authority to investigate train accidents. FRA's Office of Safety initiates investigations of serious railroad accidents and assigns members of its field force to the task of gathering factual information, determining a probable cause, and preparing a report. These reports are then submitted to the Washington, D.C., office for review and final approval. Information regarding each accident is published annually in the *Summary of Accidents Investigated by FRA*.

For the past 17 years, the author, as a regional track engineer in the southeastern United States involved with the enforcement of FRA's Track Safety Standards, has participated in many of these railroad accident investigations, particularly those in which track conditions may have been a causal factor. Special attention has been given derailments that may have been caused by insufficient lateral track stability, commonly called buckled track in the railroad industry.

Many of the potential ingredients for track buckling in continuous welded rail (CWR) are known, such as high rail temperature, poor maintenance practices during previous track work, train and dynamic braking on descending grades and in curves, and so forth.

A less-publicized consideration faced by the derailment investigator when considering the possibility of track buckling under a train after the lead locomotive has passed over the point of derailment is how and why the wheels of the first car or cars in the derailed train left the rail. Another question is why, in several cases, some rail vehicles negotiated the track at the point of derailment whereas other cars derailed. These questions need to be answered when possible causes are considered. The investigator inspects the first cars to derail, determines how the derailed wheels were positioned with respect to the track structure after they came to a stop, and notes all the wheel and flange marks at the scene. The investigator then may ask, if it is assumed that the track buckled under the train, "Would it be possible for the wheels of this loaded or empty car to derail in this manner?"

For example, one pattern noted in several derailments on curves, in which other evidence substantiated buckled track, was that loaded cars traveling in an unstable equilibrium on strong CWR track derailed to the low side, or where the wheel or wheels cross over the inner rail of a curve. Often one car derails, one or more negotiate the buckling, another derails, and so forth. In a curve the track buckles to the outside of the curve, but in the example just given the wheels derail in the short reverse curve preceding and made by the buckled-out portion of track (see Point *A*, Figure 1). The inside rail of the original curve becomes the outside rail of that small reverse curve. With a loaded car in an unstable equilibrium, the weight on the wheels on the inner rail of the curve is significantly lower than that on the outside rail (see Figure 1). About the only other situation causing a car to derail to the inside of a curve involves a train experiencing excessive draft forces resulting in a stringlining effect. Empty cars may derail because their wheels cross over either rail. On track with a weak tie condition, the wheels of loaded cars may turn either rail outward far enough to cause the cars to drop inside the track gage, or they may spread the track and all following cars will probably derail.

Given the information that a buckling could have occurred, on the basis of the presence of previously mentioned factors and the manner in which the cars derailed, it is then basic to the accident investigation to determine the maintenance history of the portion of track involved. At this point, the investigator must also determine the railroad's maintenance instructions for laying and maintaining CWR. If all or most of the facts concerning the maintenance history can be devel-

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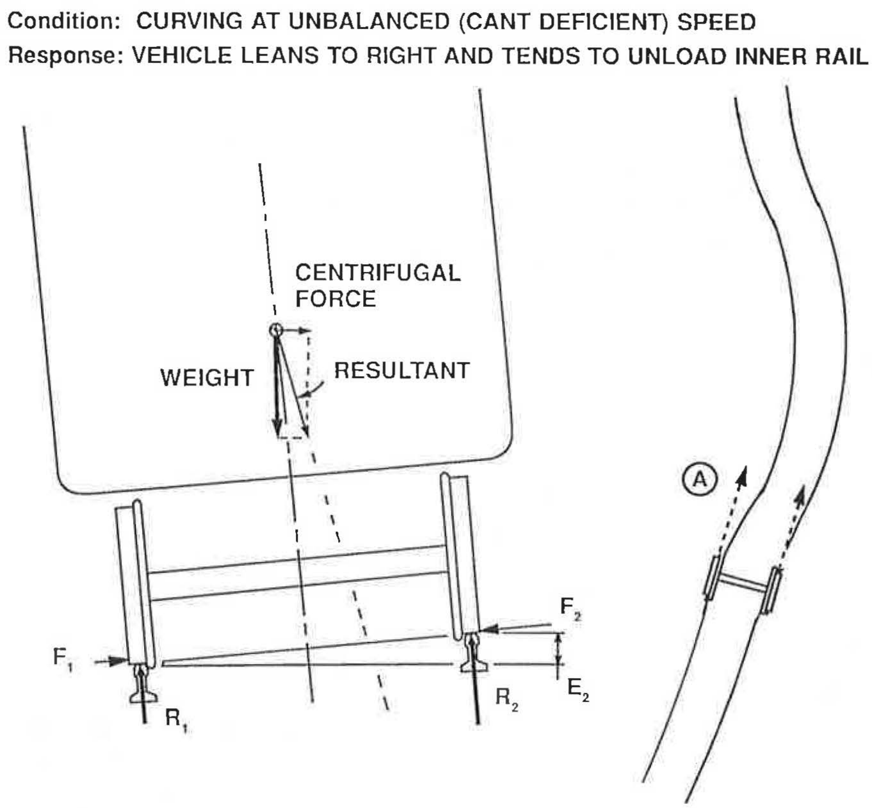

FIGURE 1 Rail vehicle negotiating a buckling in an unstable equilibrium.

oped, the following can then be determined: (a) Was the stage set for buckling by an improper maintenance practice, given a high rail temperature and forces induced by the train? (b) Were the railroad's instructions followed? (c) Did the railroad's instructions include steps to prevent this type of situation, and if so, were they clearly understood by railroad employees?

In cases in which the buckling was not seen by the train crew before the train passed over it, or in which the track in the vicinity of the point of derailment was destroyed during the accident, the probable cause is based on circumstantial evidence. All information must be considered, along with train-induced forces. Information from interviews with the train and engine crews, and from speed and event recorders, if available, must be used to determine the speed, how the train was handled, and what in-train forces may have developed. Determination of these forces is best accomplished by using a train dynamics analyzer or simulator. Given train handling scenarios, the train consist, car information, tonnage, and the track profile and curvature information, the draft or buff forces may be approximated for the car that derailed first at the point of derailment. If these forces are within a reasonable range, it may be concluded that lateral track displacement was not caused by in-train forces, but that these forces contributed to an incipient thermal buckling. To support a probable cause of track buckling that occurs under a train, the question "Why did it buckle?" must be answered.

So it is at this point that the subject of this paper, the effectiveness of various schemes in controlling the behavior of CWR, is addressed. The effectiveness may best be determined by reviewing a number of derailments in which something evidently went wrong and the track buckled. It will be determined whether existing instructions were clearly understood and followed, whether existing instructions correctly address the subject, and whether more instructions are needed on some or all railroads.

A review of the circumstances involved in 16 derailments with a probable cause of buckled track is outlined in Tables 1 and 2. In the 15-year period covered by the data in these tables, a pattern of what went wrong and how railroads changed their instructions to counter the problems can be seen. It is clear that in all cases track maintenance took place from 1 hr to 7 months before the derailment. This work resulted in too much rail in the track or, in other words, a significant reduction in neutral temperature, to below that desired to prevent buckling caused by relatively high temperatures and train-induced forces. Neutral temperature is defined as the rail temperature at which anchored CWR is free of longitudinal stress, that is, not in tension or compression. Railroads endeavor to install or adjust CWR to an optimum neutral temperature for the geographical area, so that it will withstand the extreme heat and cold. In Georgia, for instance, the desired neutral rail temperature is between 90 and 100°F.

Ten of the 16 derailments involved descending grades where the train was braking at the time of derailment or where previous trains had braked. Dynamic, independent, and automatic train braking all cause significant longitudinal rail movement on track that has been recently disturbed by maintenance. This movement occurs even on track with the usual number of rail anchors. When the ballast is disturbed, it does

TABLE 1 ACCIDENT SUMMARY

						Slow Order	
Derailment No.	Descending Grade	Recent Work	Rail Creep	Curve or Tangent	Chording a Factor	Not Placed	Not on Long Enough
1	Yes	Yes	Yes?	C	?	X	
2	Yes	Yes	Yes	T	No		X
3	No	Yes	Yes	T	No		
4	No	Yes	No	C	Yes		
5	Yes	Yes	Yes	T	No		
6	Yes	Yes	No	C	Yes		
7	Yes	Yes	No	C	Yes		
8	Yes	Yes	No	C	Yes		
9	Yes	Yes	No	C	No		
10	Yes	Yes	No	C	Yes		
11	No	Yes	Yes	T	No		
12	No	Yes	No	T	No		
13	Yes	Yes	Yes	T	No	X	
14	Yes	Yes	No	C	No	X	
15	No	Yes	No	C	Yes		
16	No	Yes	No	C	Yes		
Total	10 yes	16 yes	6 yes		7 yes		

Blanks indicate either slow order was placed, or since considerable time had passed sinced maintenance work a slow order did not remain in effect.

not have enough resistance to overcome the longitudinal force transmitted to it by the ties. In this paper, such movement will be called longitudinal creep. At places where creep is impeded, compressive stress builds up in the CWR, or tensile stress is decreased if the rail is in tension. These places include turnouts, vertical curves at the bottom of grades, horizontal curves, and bridge approaches. The neutral temperature at those locations is reduced to below the desirable temperature. At high temperatures thermally induced, static, longitudinal compressive forces build up, and a train traversing the location contributes sufficient dynamic forces, both longitudinal and lateral, to cause buckling, the amplitude of which is increased with the passage of the cars in the train. In 4 of the 10 derailments on descending grades, it appears that rail creep was a significant factor in causing the buckling. It was also a factor in two derailments on level track.

On the basis of this experience, it appears that railroads have a problem in adequately controlling creep even though rail anchors are applied to their respective standards. What controls do railroads have? Longitudinal rail creep may be reduced by slowing train speeds and reducing braking forces until the ballast has been compacted by several tonnage trains. Some railroads use a machine method of ballast consolidation, such as dynamic stabilizers or compactors, to simulate track vibration induced by train movements and reduce the necessity for slow orders. The application of additional rail anchors in areas where heavy braking is expected aids in reducing creep. In the six cases discussed in which rail creep was a factor, the controls failed for several reasons. In two cases, a slow order was never placed; in one case it evidently was not in force long enough. In the other cases it is not known if or how long orders were in force. In the two cases in which an order was not placed, the carrier had slow order requirements, but they were not clearly understood by the people performing the work. Rail creep has been and remains a major problem. All railroads need to review their instructions to see that creep is properly addressed, particularly at those critical locations mentioned previously.

In 7 of the 10 derailments that occurred in curves, one of two conditions, or a combination of both, evidently existed:

1. After track on a curve was disturbed by maintenance that reduced lateral and longitudinal stability, the curve shifted inward (chorded in) during cold weather before the ballast section was restored or was sufficiently compacted by train movements, and the track stayed in this position until the time of derailment.

2. During a surfacing and alinement procedure at cool temperature, the curve was thrown inward more than outward. In one derailment investigation this was documented through comparison of string line notes before and after the curve was lined. This phenomenon may also be determined by comparing track geometry car information before and after alinement work.

TABLE 2 REVIEW OF CIRCUMSTANCES OF DERAILMENTS

DATE, TIME AND AMBIENT TEMPERATURE IN F°	ALINEMENT AT POINT OF DERAILMENT RAIL, GRADE (D-DESCEND, A-ASCEND)	TRAIN HANDLING METHOD AND SPEED	FIRST CARS IN TRAIN TO DERAIL	TRACK MAINTENANCE HISTORY	RAILROAD INSTRUCTIONS	REASON FOR BUCKLING
(1) MAY 1974 1:05 P.M. 86°	3° CURVE 115 CWR 0.96% D	THROTTLE, NO BRAKING. 58 MPH	1ST PASSENGER CAR PLUS 10 FOLLOWING	THE DAY OF THE ACCIDENT 14 TIES REPLACED IN 50 FT., AND TRACK SURFACED.	SLOW ORDER TO BE PLACED WHEN TIMBERING AND SURFACING.	CWR DISTURBED HIGH TEMPERATURE AND NOT PROTECTED BY SLOW ORDER. NO WAY OF KNOWING NEUTRAL TEMPERATURE.
(2) JULY 1980 3:35 P.M. 99°	TANGENT 132 CWR. AT LEAVING END OF BRIDGE 0.3% D	53 MPH	72ND, MTY, PLUS 39 FOLLOWING CARS	FIVE DAYS BEFORE ACCIDENT THE TRACK OFF THE END OF 60-FOOT OPEN DECK THRU PLATE GRINDER (NOT ANCHORED) WITH 156 FT. BALLAST DECK APPROACH WAS SPOT SURFACED. TRACK TIED AND SURFACED IN FEB. 1980 AT 26°.	SLOW ORDER TO BE PLACED WHEN SPOT SURFACING ABOVE 85°. THIS WAS DONE, BUT ORDER LIFTED BEFORE DERAILMENT.	LONGITUDINAL CREEP, WHEN SURFACED, LOWERED NEUTRAL TEMPERATURE AT END OF BRIDGE. BUCKLE OCCURRED UNDER TRAIN.
(3) JULY 1980 6:55 P.M. 93°	TANGENT 136 CWR. JUST AHEAD OF RAILROAD CROSSING DIAMOND. LEVEL	42 MPH	10TH, MTY, PLUS 18 FOLLOWING	RAIL CROSSING DIAMOND RENEWED IN JANUARY, ALSO SURFACED THEN AT 49°. A 60-FOOT OPEN DECK BRIDGE AHEAD OF AND NEAR DIAMOND. NO ANCHORS ON BRIDGE.	NONE	WHEN THE CWR WAS CUT TO INSTALL CROSSING, RAIL CONTRACTED ACROSS UNANCHORED BRIDGE, AND TOO MUCH RAIL ADDED LOWERING NEUTRAL TEMPERATURE. THERE WAS ONE INCH OF RAIL MOVEMENT ACROSS THE BRIDGE.
(4) JUNE 1982 3:34 P.M. 90°	2° CURVE 132 CWR. LEVEL	NO. 5 THROTTLE, NO BRAKE. 50 MPH	6TH CAR, A LOADED TRI-LEVEL TO LOW SIDE, PLUS FOLLOWING 15 CARS	TRACK SURFACED IN OCT. 1981, WHEN LOW TEMPERATURE REACHED 29°.	NONE	CWR EVIDENTLY CHORDED INWARD DURING OR AFTER SURFACING, REDUCING NEUTRAL TEMPERATURE AND STAYED IN THIS POSITION UNTIL BUCKLED UNDER TRAIN ON A DAY WHEN TEMPERATURE WAS ONE OF THE HIGHEST SINCE OCT.
(5) MARCH 1985 12:30 P.M. 76°	TANGENT 132 CWR. JUST AHEAD OF FACING POINT TURNOUT 0.7% D	NO. 7 DYNAMIC BRAKE. 46 MPH	77TH, MTY, 80TH, LOAD, THRU 100TH.	NEW TURNOUT INSTALLED IN DEC. 1984. WHEN SURFACED IN FEBRUARY, LOW TEMPERATURE WAS BETWEEN 28° AND 57°.	NONE	WHEN TURNOUT INSTALLED AND RAIL WAS CUT, IT EVIDENTLY CONTRACTED BECAUSE OF COOL TEMPERATURE, TOO MUCH RAIL MAY HAVE BEEN ADDED. CREEP MAY HAVE ALSO OCCURRED DURING AND AFTER SURFACING. TRACK BUCKLED UNDER TRAIN IN DYNAMIC BRAKING MODE.
(6) JULY 1985 3:42 P.M. 93°	3° CURVE 132 CWR. JUST OFF LEAVING END OF 600-FT. OPEN DECK BRIDGE (ANCHORED). 0.44% D	NO. 6 THROTTLE WITH 12 LB. AUTOMATIC BRAKE PIPE REDUCTION. 43 MPH	28TH CAR, LOAD, TO INSIDE OF CURVE, THRU 60TH CAR.	CURVE ON LEAVING END OF BRIDGE UNDERCUT IN FEB. 1985, WHEN LOW TEMPERATURE REACHED 15°. SURFACED SAME MONTH WITH TEMPERATURE RANGE 25° TO 53°.	NONE	WHEN TRACK WAS UNDERCUT AND SURFACED, APPARENTLY CWR CHORDED INWARD AND STAYED IN THIS POSITION UNTIL BUCKLED UNDER TRAIN IN TRAIN BRAKE MODE AT HIGH TEMPERATURE. CREW SAW SOME MISALINEMENT ON APPROACH TO SCENE.
(7) MARCH 1986 2:50 P.M. 77°	6° 15' CURVE 132 CWR 1% D	NO. 3 DYNAMIC BRAKE. 40 MPH	LEAD WHEELS OF 47TH CAR, LOAD, DERAILED TO INSIDE OF CURVE. TRAILING TRUCK OF 48TH, AND 49TH THRU 83RD DERAILED.	OUTSIDE RAIL OF CURVE HAD BEEN LAID AND HEATED TO 100° IN DEC. 1985. CURVE SURFACED IN FEB. 1986, DURING PERIOD WHEN TEMPERATURE REACHED AS LOW AS 17°.	NONE	CURVE SURFACED DURING COOL WEATHER AND CHORDED INWARD. BALLAST WAS ADDED AND TRACK COMPACTED BY TRAINS IN THIS POSITION. TRACK STAYED AT THIS LOCATION UNTIL IT BUCKLED OUT ON WARM DAY UNDER TRAIN.
(8) MAY 1986 3:40 P.M. 91°	4° 30' CURVE 132 CWR 1% D	NO. 4 DYNAMIC BRAKE. 30 MPH	60TH, MTY, LEAD TRUCK DERAILED TO OUTSIDE, 61 AND 62 STAYED ON, 63RD, LOAD, SPREAD THE TRACK. THE 64TH THRU 76TH DERAILED.	CURVE WAS SURFACED IN FEB. 1986, WHEN TEMPERATURES REACHED AS LOW AS 17°. CURVE NOTES ALSO INDICATED, WHEN ALINEMENT MADE AFTER SURFACING, THAT TRACK WAS LINED IN MORE THAN OUTWARD.	NONE	CURVE SURFACED DURING COOL WEATHER AND CHORDED INWARD. BALLAST WAS ADDED AND TRACK COMPACTED BY TRAINS IN THIS POSITION. STAYED AT THIS LOCATION UNTIL IT BUCKLED UNDER TRAIN. LINING INWARD MAY HAVE CONTRIBUTED.
(9) JUNE 1986 3:47 P.M. 92°	2° CURVE 112 & 115 CWR. 0.77% D	NO. 6 THROTTLE WITH MINIMUM TRAIN BRAKE REDUCTION.	63RD, LOAD, SPREAD THE TRACK. BALANCE THRU 86TH DERAILED.	THE OUTER RAIL OF CURVE WAS LAID IN MARCH WITHOUT HEATING WHEN TEMPERATURE RANGED BETWEEN 35° AND 53°.	CWR TO BE HEATED WHEN LAYING TO A RAIL TEMPERATURE OF 80°.	RAIL INSTALLED AND ANCHORED AT A LOW NEUTRAL TEMPERATURE. TRACK BUCKLED UNDER HEAVY TRAIN.
(10) JUNE 1986 3:10 P.M. 93°	6° CURVE 132 & 136 CWR. 1.2% D	NO. 8 DYNAMIC BRAKE. 35 MPH	53RD, LOAD, TO INSIDE, 63RD, LOAD, TO INSIDE PLUS 54 MORE CARS.	THE OUTER RAIL OF THE CURVE WAS LAID IN DEC. 1985, AND HEATED TO 95°. IN MARCH 1986, ONE INCH OF ELEVATION WAS REMOVED FROM THE CURVE BY SURFACING AT A TEMPERATURE BETWEEN 49° AND 59°. A FEW DAYS LATER, THE LOW REACHED 22°.	CWR TO BE HEATED WHEN LAYING TO A TEMPERATURE OF AT LEAST 80°. NONE ON SURFACING DURING COOL WEATHER.	THE REMOVING OF ELEVATION REDUCED LATERAL RESTRAINT. DURING PERIOD OF COLD WEATHER SHORTLY AFTERWARD CURVE EVIDENTLY CHORDED INWARD AND STAYED IN THIS POSITION UNTIL IT BUCKLED UNDER TRAIN IN HEAVY DYNAMIC.

TABLE 2 *(continued on next page)*

TABLE 2 (*continued*)

DATE, TIME AND AMBIENT TEMPERATURE IN F°	ALINEMENT AT POINT OF DERAILMENT RAIL, GRADE (D-DESCEND, A-ASCEND)	TRAIN HANDLING METHOD AND SPEED	FIRST CARS IN TRAIN TO DERAIL	TRACK MAINTENANCE HISTORY	RAILROAD INSTRUCTIONS	REASON FOR BUCKLING
(11) JULY 1986 4 P.M. 90°	TANGENT AT LEAVING END OF 670-FOOT OPEN DECK TRESTLE. 115 CWR. LEVEL	NO. 8 THROTTLE. 47 MPH	79TH, LOAD, PLUS 11 FOLLOWING. CARS EVIDENTLY SPREAD THE TRACK.	IN JUNE, FOULED BALLAST WAS STRIPPED OUT AND FRESH BALLAST APPLIED FOR 25 FEET AT LEAVING END OF BRIDGE. CWR ON BRIDGE DID NOT HAVE RAIL ANCHORS.	NO SPECIFIC INSTRUCTIONS CONCERNING ANCHORS ON CWR ON BRIDGES OVER 300 FT. SLOW ORDER WAS LEFT ON FOR 24 HOURS AFTER TRACK WORK IN JUNE.	EVIDENCE INDICATED 2 5/8 INCH LONGITUDINAL RAIL MOVEMENT ON TRESTLE. RAIL EXPANDED ON UNANCHORED BRIDGE REDUCING NEUTRAL TEMPERATURE WHERE TRACK WORK TOOK PLACE. TRACK BUCKLED AT THAT POINT UNDER TRAIN.
(12) JULY 1986 4:10 P.M. 98°	TANGENT 132 CWR. LEVEL	NO. 5 THROTTLE. 18 MPH	69TH, LOAD, PLUS NEXT 7 CARS.	CWR WAS LAID IN 1983 AND 1984, TRACK ALINEMENT AND SURFACE WAS IRREGULAR AT TIME. SURFACED AND LINED IN AUG. 1985. IN WINTER PREVIOUS TO DERAILMENT, NUMEROUS SHORT RAIL PLUGS WERE CUT INTO REMOVE DEFECTIVE RAIL & FIELD WELDS MADE AT TEMPERATURES AS LOW AS 24°.	NONE THAT WERE SPECIFIC.	STRAIGHTENING IRREGULAR ALINEMENT AND SURFACE WOULD LOWER NEUTRAL TEMPERATURE. CUTTING CWR AND WELDING IN PLUGS WITHOUT ADJUSTMENT IN COLD WEATHER WOULD ADD TOO MUCH RAIL TO THE TRACK. TRACK BUCKLED UNDER TRAIN.
(13) JULY 1986 4:24 P.M. 90°	TANGENT, 132 CWR AT RECEIVING END OF 164-FOOT OPEN DECK BRIDGE WITH ANCHORS. 0.2% D	NO. 5 THROTTLE. 45 MPH	24TH, LOAD, TURNED RAIL OVER, 25TH, MTY, CROSSED OVER RAIL, 26TH THRU 38TH DERAILED.	CWR SURFACED A FEW HOURS BEFORE THE DERAILMENT WITH RUNOFF MADE TO END OF BRIDGE. NO SLOW ORDER PLACED ON TRACK.	RULE REQUIRES SLOW ORDER AFTER SURFACING OVER 85°, BUT WAS MISUNDERSTOOD BY TRACK WORKERS.	LATERAL RESTRAINT WAS REDUCED BY SURFACING AT HIGH TEMPERATURE WHEN NEUTRAL RAIL TEMPERATURE WAS UNKNOWN. RAIL CREEP BY TRAIN INVOLVED AND PREVIOUS TRAINS HAD LOWERED NEUTRAL TEMPERATURE RESULTING IN BUCKLE UNDER TRAIN.
(14) AUG. 1986 3 P.M. 90°	3° CURVE 100 CWR. 0.7% D	NO. 8 DYNAMIC BRAKE. 32 MPH	92ND, MTY, TO LOW SIDE, 95TH, MTY, ONE TRUCK TO HIGH SIDE, 96TH, MTY, ONE TRUCK TO LOW SIDE, 98TH, LOAD, TO LOW SIDE PLUS 120TH THRU 123RD.	THE DAY PRIOR TO THE DERAILMENT, A TRACK GANG SURFACED THE TRACK AT 91° AND DID NOT PLACE A SLOW ORDER.	CLEAR INSTRUCTIONS WERE NOT AVAILABLE TO FOREMAN IN CHARGE.	TRACK SURFACING REDUCED LATERAL RESTRAINT. TRACK BUCKLED UNDER TRAIN IN DYNAMIC BRAKING MODE. SLOW ORDER WAS NOT PLACED AND THE NEUTRAL RAIL TEMPERATURE WAS UNKNOWN.
(15) APRIL 1987 2:35 P.M. 83°	1° 47' CURVE 122 CWR LEVEL	NO. 8 THROTTLE. 25 MPH, CREW FELT LURCH OVER P.O.D.	20TH, LOAD, CROSSED OVER OUTER RAIL, 22ND, 24TH, 29TH THRU THE 53RD DERAILED.	THREE DAYS PRIOR TO THE DERAILMENT, A TIE GANG INSTALLED TIES AT 50° TO 57°. BALLAST SECTION WAS NOT FULLY RESTORED.	NO REFERENCE STAKES SINCE THE INSTRUCTIONS WERE TO STAKE CURVE OVER 1° IF WORKED UNDER 50°. 25 MPH ORDER PLACED ON TRACK.	CURVE SHIFTED INWARD AFTER DISTURBING DUE TO COOL TEMPERATURE, AND INADEQUATE BALLAST SECTION. TRACK BUCKLED ON WARM DAY UNDER LOCOMOTIVES.
(16) AUG. 1988 2:55 P.M. 95°	6° 50' CURVE. 132 & 136 CWR LEVEL	NO. 6 THROTTLE. 34 MPH CREW SAID THEY SAW BUCKLE.	24TH, LOAD, SPREAD TRACK. 25TH THRU 53RD DERAILED.	FOUR DAYS PRIOR TO THE DERAILMENT, TRACK WAS SURFACED BETWEEN 70° AND 80°. THE DAY PRIOR TO THE DERAILMENT, THE LOW REACHED 56°.	NO REFERENCE STAKES SET SINCE IT WAS OVER 50°. A 25 MPH WAS ON TRACK IN THIS AREA AND TRAIN SHOULD HAVE BEEN COMPLYING.	CURVE SHIFTED INWARD DURING COOL TEMPERATURES AFTER BEING DISTURBED BY SURFACING. BUCKLED BEFORE TRAIN ARRIVED AT 95° THE HIGHEST TEMPERATURE SINCE SURFACING.

Both of the above conditions may reduce the rail neutral temperature to an undesirable level. The shifting due to cold temperatures may sometimes be observed by inspection, but it often is so uniform that it goes unnoticed.

It should be noted that curves may shift inward during cold temperatures, even if the ballast section was not recently disturbed. This has occurred at locations where the shoulder ballast section on the inside of curves is not sufficient to resist the chording effect from tension that developed at extremely cold temperatures, even though the rail may have been at the desired neutral temperature before it moved inward. Curves may also shift if some recent rail maintenance work (in which no ballast was disturbed) caused a change of neutral temperature to a level higher than desirable, for instance, if rail was installed at, or overheated to, a rail temperature of 125°F. When the rail later cools, high tensile forces in the CWR cause the track in the curve to overcome the lateral resistance of even a well-compacted ballast section and shift inward.

The chording phenomenon, caused by high tensile forces in the CWR, could also be aided by a dynamic stringlining effect that results from large draft forces that develop in trains being pulled up a grade while on a relatively sharp curve. A neutral temperature that is too high may also result in the pulling apart of CWR at a joint or its breaking at a stress riser during cold weather.

One railroad in the South recognized the curve-shifting problem in CWR track many years ago and has instructions to compensate for the problem. Before track on a curve is surfaced or otherwise disturbed at or below a rail temperature of 50°F, reference stakes are set at several locations around the curve. The amount of movement at each stake is recorded one week after the curve is surfaced. If there is an average

movement of 1 in. or more, the track must be lined out or slow ordered before hot weather.

As stated earlier, an analysis of the 10 of 16 derailments that occurred in curves showed that 7 of the curves evidently chorded inward during or shortly after surfacing during a period of cool weather.

Reference stakes were not set in any of the cases. Two derailments occurred after the railroad issued reference stake instructions. Stakes were not set because on the days of surfacing, the temperature was more than 50°F. In several cases it was noted that the temperature was near 50°F at the time of surfacing, but dropped within a few days after surfacing and before the ballast was adequately dressed or sufficiently compacted by train traffic. It is entirely possible that all seven derailments could have been prevented had the staking procedure been followed. It is therefore concluded that whenever work involving CWR (laying rail, surfacing, undercutting, or installing ties) is performed in curves, a controlled method for measuring lateral track movement must be set up before the work begins, so that any appreciable change in alinement that occurs during the work or before the ballast is properly consolidated can be recorded. Adjustments can then be made before hot weather. Railroads that do not have these controls should consider instituting them. Railroads that have instructions for staking when the temperature is less than 50°F should consider the consequences of a temperature that is more than 50°F on the day of the work and drops in the next few nights before the ballast has been consolidated.

Once the chording phenomenon on curves is understood, another possibility must be considered. When a curve is disturbed and lined at extremely high temperatures, it can be lined to the outside with relative ease. If this is overdone, the neutral temperature may be raised too high, as in the previously mentioned overheating of the rail during installation. If the rail stays hot until the ballast has consolidated, the track on the curve will stay in this position until it turns cold and the tension becomes so great that it overcomes the restraining friction force of the ballast and chords inward, thus possibly lowering the neutral temperature to below that desirable. The greater the degree of curvature, the greater the forces trying to shift the track inward. Again, controls must be in place to monitor this type of situation.

In derailments 1, 13, and 14 the temperature was high when the maintenance work was performed, no slow order was placed, and the accidents occurred at locations susceptible to buckling—two on curves and one on a bridge approach. Some previous event at these locations reduced the neutral temperature to below the desirable level, causing the rail to be under considerable compression in the hot weather at the time of the derailments. The disturbance of the ballast by the recent work reduced the lateral track restraint, and the addition of train-induced forces buckled the track. In those three cases the railroad employees at the scene did not correctly understand the instructions for placing slow orders during hot weather. A slow order either would have prevented the derailments or at least would have reduced the damage caused by the derailment.

When railroad personnel do not know the rail neutral temperature, they do not know if they are disturbing the track above that temperature. Therefore the track must be covered with a slow order after it has been disturbed. Instructions calling for a slow order at temperatures near the desired neutral temperature for the area may not be sufficient. This consideration, along with the possibility of increased longitudinal rail creep with increased speed, raises the question of whether slow orders should be placed, regardless of temperature, after the track has been disturbed and left in place until the ballast has consolidated.

Derailments 3, 5, and 12 involved cutting CWR during periods of low rail temperature. In Derailment 3, a new railroad crossing diamond (frogs) was installed during cool weather several months before the derailment. Evidently, when the CWR was cut to take out the old diamond, the rails contracted, and too much rail was added when the new diamond was installed. Immediately in the approach to the rail crossing was a 60-ft open-deck bridge on which no rail anchors were installed. The rail creep caused by the rail expansion across the bridge and the impeding effect of the diamond resulted in the build-up of compressive stress on the ballasted track, which in turn caused the neutral temperature to be below the desired level. The track buckled under a train at an ambient temperature of 93°F on a short stretch of ballasted track between the bridge and the diamond.

In Derailment 5 an old turnout was removed from the CWR track, and a new one was installed and surfaced in cold weather. Too much rail may have been added because of contraction after the CWR was cut, resulting in a lowering of the neutral temperature. This was a facing point turnout for trains on a descending grade; therefore longitudinal rail creep, impeded at the turnout, would further decrease the neutral temperature in the approach to the turnout. Several warm days occurred between the time of the track work and the derailment, but no trains operated during those days. The first train over the track during the heat of the day, in a heavy dynamic braking mode, derailed just ahead of the switch of the turnout because of an apparent buckle.

Derailment 12 involved a situation in which relay CWR was installed 2 to 3 years before the derailment, which occurred in July at an ambient temperature of 98°F. During the previous winter numerous field welds had been made, in which rail plugs were added to remove poor and defective sections of rail. The cutting of the rail occurred at low temperatures, and evidently no allowance was made for the rail's contracting. Thus, too much rail was added, lowering the neutral temperature. It was also learned that at the time the CWR was laid to replace the jointed rail, the alinement and surface were irregular. The track was later surfaced and lined. This would have had the effect of adding more rail and would have further reduced the neutral temperature, even if the rail had been laid at the desired temperature for the area.

Several examples are similar to this one, in which CWR was installed at the desired neutral temperature, but with irregular alinement and surface. When the track was later straightened by lining and surfacing, buckling occurred during hot temperatures. Some carriers do not address this problem in their instructions and do not correctly adjust the rail after it has been cut during cold weather.

Five of the derailments took place near the ends of open-deck bridges. As previously discussed, this is a critical location, at which longitudinal rail creep is impeded and a lower neutral temperature can be expected. Whenever this track is disturbed in hot weather, problems should be anticipated, as in Derailments 2, 11, and 13.

In Derailment 2, a slow order was placed at the time of

disturbance but was later lifted. Five days later, in extreme heat, the track at the end of a bridge buckled under a train. In Derailment 11, no rail anchors were found on the 670-ft open-deck trestle, and evidence showed up to 2⅝ in. of longitudinal rail movement on the bridge. This expansion across the bridge at a high temperature would have caused longitudinal creep and high compressive forces at the end of the bridge where the track had been disturbed the month before the derailment. The railroad had no specific instructions about anchoring on bridges with CWR over 300 ft. Some allowance has to be made in these cases to account for longitudinal movement. The railroad later applied rail anchors across this trestle. Each structure must be evaluated by bridge specialists to determine the best method of handling rail expansion for that particular structure. In Derailment 13, the track was surfaced at the approach to a 164-ft open-deck bridge with rail anchors just hours before the derailment. No slow order was in place. The bridge in this case impeded rail creep that had caused a lowering of neutral temperature both in front of and under the train that derailed.

Derailment 9 involved laying the outside rail of a curve with CWR and removing jointed rail. The inside rail remained as jointed rail. The rail was laid at cool temperatures in March, and instructions for heating the rail were not followed. Rail anchors were not added to the inner rail, so anchors were not on the same ties as those installed on the newly laid CWR, reducing the rigidity of the track structure. The track buckled under a heavy train at a high temperature in June.

Over the past 15 years instructions for controlling the behavior of CWR have improved from an annual spring letter from a chief engineer stating, "Don't let the track buckle," to 50-page booklets of instructions for almost every type of situation. The question remains whether some railroads are still just beginning to give instructions and training to personnel in controlling the behavior of CWR. At a minimum, every railroad should have clear instructions regarding slow orders, laying and adjusting CWR, staking curves, anchoring rail, cutting and welding CWR, handling rail pull-aparts in winter, and taking care of rail expansion on structures. Furthermore, a training program must be in place to ensure that personnel involved with CWR maintenance understand the application of these instructions.

A track foreman may not understand the physical principles involved or exactly what is meant by desired neutral temperature, but he does understand that if a piece of irregular track is lined and surfaced, there may be too much rail in that track. Also, if a piece of rail is removed, at a minimum, the same amount of rail must be replaced. The rail may not be adjusted to the desired neutral temperature, but conditions will not be worsened.

How is the effectiveness of the various schemes to control CWR summarized? Experience has shown what went wrong and what should have been done to prevent derailments. There has been an improvement and at least a reduction in derailments caused by track buckling.

If the instructions of several different railroads are reviewed collectively, it is found that most of the problems addressed in this paper are covered to some extent by at least one railroad. Each railroad is urged to take the best instructions from the others to cover the whole spectrum of potential situations. After this has been done, the challenge remains to make sure the people doing the work are trained to understand and follow those instructions.