Railways of Australia Track Buckling Project

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The Queensland Railways undertook from 1986 through 1988 a major civil research project on track buckling on behalf of the Railways of Australia. From this project was developed a system that enables a railway system to reduce the probability of track buckling on its line sections. The elements of the track buckling prevention system, neutral temperatures of rail, theoretical aspects of safe operating temperatures, and the use of the Association of American Railways theoretical track buckling model to investigate the stability of a track standard are discussed.

Buckling of tracks has been a particular concern to engineers and administrators at the Queensland Railways during the last decade, and early in 1986 it was recognized that positive action was necessary to reduce its occurrence.

In July 1986, the Queensland Railways were commissioned by the Railways of Australia to undertake a research project on track buckling. The basic objectives were to (a) review the information available from within the state railway systems on track buckling, with particular emphasis on causes and procedures currently used to reduce its probability of occurrence, and (b) formulate recommendations and develop a practical track buckling prevention system to reduce the probability of track buckling occurrences.

A Railway of Australia report provides specific details of the project, the findings, and the track buckling prevention system (*1*). The project, as discussed by Hagaman and Heywood (*2*) and Hagaman and Kathage (*3*), was undertaken in two stages, each involving development, trial, and refinement of the track buckling prevention system. Validation of the prevention system was undertaken using the findings of overseas research, parametric studies using an analytical track buckling model, track buckling statistics collected in Australia, and the trial of the system in Queensland and Western Australia.

RAILWAYS OF AUSTRALIA PROJECT

Stage 1 of the project involved

- A review of existing maintenance practices on tracks with continuous welded rail (CWR), long welded rail, and short jointed track, particularly maintenance and operational procedures adopted during critical high ambient temperature conditions;
- A review of existing track buckling statistics available from Australian states and collection of additional data for validation of the buckling prevention system;
- Examination of existing track stability rating systems;
- A literature review; and
- The development and trial of an empirical track buckling prevention system based on the derived track stability rating and recommended maintenance and operational practices.

Stage 2 involved

- Validation of the buckling prevention system from a practical view,
- A review of existing buckling models and theoretical work,
- Implementation of the refined system on selected track districts in all states during the 1987–1988 summer, and
- Examination of buckling-related derailments and traffic operating practices.

Extensive monitoring was conducted after the completion of the project, particularly in Queensland, to evaluate the worth of the study in reducing track buckling occurrences and the practicality of the track buckling prevention system.

TRACK BUCKLING PREVENTION SYSTEM

The track buckling prevention system is designed to reduce the likelihood of buckling by allowing maintenance staff to perform their duties according to the system's main components:

1. The Maintenance Timetable, which indicates the recommended track work to be performed each month;
2. The Management Guidelines, which are a set of instructions to crews describing the preparations, precautions, and follow-up actions to be taken when performing various types of track work;
3. The Track Condition Report, which is produced from an annual inspection and provides a list of locations requiring remedial work to avoid buckling, along with the relative probability of buckling at each location;
4. The Track Maintenance Progress Report, which is a method of ensuring that items 1, 2, and 3 are being performed at the correct time of the year; and
5. An assessment of the adequacy of any existing track design standard for buckling resistance.

The field trials have shown that the timing of the various steps of the track buckling prevention system is fundamental

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to the system's success, and hence the Track Maintenance Progress Report is necessary. It is imperative that each step start at the correct time so that the remedial track work is completed before the start of summer.

The Maintenance Timetable and Management Guidelines together with the Track Maintenance Progress Report are sufficient to minimize the buckling problem in a railway system. This assumes that sufficient manpower and funds are available during the year to perform the work necessary to maintain the track to the chosen standard. However, the trend in track maintenance in all Australian railway systems in recent years has been toward an overall reduction in staff through the introduction of specialized migratory gangs and the use of outside contractors.

In response to this general need to minimize track maintenance costs, the Track Condition Report was developed. The aim of this report is to achieve a safe, stable track at minimum cost. An annual list of priority work that is used to direct maintenance staff to only those areas in need of urgent attention is produced.

The report procedure enables the district civil engineer to become aware of potential problem areas and to determine how best to organize limited maintenance resources to perform urgent work before the start of summer. The rating method used in the Track Condition Report does not attempt to assign absolute values for the buckling stability of the track, but simply locates the least stable spots within some convenient length of track. The rating is essentially a comparative method. It assumes that the rail system's chosen track standard for both curved and tangent track is adequate to hold the track securely against buckling through the expected temperature range, provided that the actual neutral stress temperature of the rail is within defined limits of the design neutral temperature. The adequacy of the design track standard can be investigated by use of an analytical buckling model.

Maintenance Timetable

Recommended in the timetable for track maintenance is the programming of maintenance activities most appropriate for each season. For example, maintenance of rail joints should be conducted before summer begins. Maintenance activities that disturb the track, such as resurfacing and resleepering, are recommended for the cooler months if track standards are not adequate.

The recommended timetable for maintenance activities in tropical and subtropical regions is shown in the following table.

Activity	*Timetable*
CWR stress adjustment	March to October
Rail joint maintenance	March to May, August to October
Expansion adjustment and anchor application	August to November
Lifting and packing near fixed track structures	March to September, remainder of year in early morning only
Resleepering	March to August, September and October in early morning only
Ballast profile and formation widening	All year, especially November to February

Management Guidelines

The regular maintenance practices that are normally required of track staff are formalized in the Management Guidelines. Aspects of both jointed and welded track are covered, including

- General maintenance of track components;
- Rail joint maintenance and surveillance;
- Rail gap and steel regulation of welded rail;
- Formation and ballast profile maintenance;
- Mechanized resurfacing, pulling, or lifting of the track;
- Operations performed on a face, such as mechanized resleepering or track relaying; and
- Use of rail anchors or indirect fasteners.

If track-disturbing work is performed at high temperatures, trains are subject to a speed restriction in order to allow reconsolidation of the ballast. Prohibition of certain maintenance activities is governed by the track standard, the work site temperature, and predicted climatic conditions for the following days. As such, the distribution of temperature forecasts and the monitoring of work site rail temperatures are important elements of the summer monitoring of areas prone to buckling.

Track Condition Report

For instances in which resources are not available to undertake remedial work in accordance with the maintenance timetable and the management guidelines, a track condition reporting and rating procedure was developed.

The Track Condition Report is produced from an annual inspection of the track condition against the design standard. Data from this inspection are entered into the dBASE III program RATING, developed for use on an IBM personal computer or compatible. From this program are produced a relative track buckling rating and a list in priority order of locations where remedial work is required to reduce the probability of track buckling on the line section. A sample output from the rating program is shown in Figure 1.

The track condition rating assumes that the rail system's design standards for both curved and tangent track are adequate to resist buckling. This assumption can be verified by use of an analytical track buckling model, and the rating cutoff level for urgent remedial work can be reduced accordingly for cases in which any deficiency in the design standard is identified.

The rating ranges from 0 to 100 and is a relative comparison of the actual track condition and the design track standard. A rating of 100 represents a high resistance to buckling. The rating automatically takes into account different track standards for curved and tangent track by comparison with the design standard. For example, a rating of 60 on curved track would represent higher track stability than a rating of 60 for tangent track, but would represent the same probability of buckling.

The track condition rating program RATING has been validated by in-track trials, examination of statistical data on buckling occurrences, and use of the Association of American

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                                          PRIORITY TRACK MAINTENANCE LIST
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LINE           LOCATION           BUCKLING  RESISTANCE
                 (KM)             POTENTIAL     RATING   TYPE OF WORK REQUIRED

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** ACTION REQUIREMENT LOW PRIORITY.
ATEST                12.0 -   12.5         3      91.0   ,,,,

** ACTION REQUIREMENT URGENT
ATEST                11.0 -   11.5        74      65.0   FREE JOINTS,ADJUST RAIL &
                                                         ANCHOR,,BALLAST,SLEEPERS/FASTENERS

ATEST                10.5 -   11.0        73      68.0   FREE JOINTS,ADJUST RAIL & ANCHOR,,BALLAST,

ATEST                10.0 -   10.5        72      71.0   ,ADJUST RAIL & ANCHOR,,BALLAST,

ATEST                11.5 -   12.0        67      83.0   FREE JOINTS,ADJUST RAIL & ANCHOR,,
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FIGURE 1 Sample output of the RATING program.

Railways (AAR) buckling model, TRACK. AAR provided the model for testing and evaluation during this project.

RATING was specifically designed to allow rail systems to modify the relative rating components or formula should alternative input parameters or resistance relationships be desired. At present RATING takes account of the following parameters for which data are required to be collected in the field during the annual track inspection.

- Rail
  - –Size,
  - –Temperature (for correct joint gap calculation),
  - –Length,
  - –Actual joint gap, and
  - –Frozen joints;
- Ballast
  - –Shoulder,
  - –Deficiency at shoulder,
  - –Deficiency at crib,
  - –Depth, and
  - –Type;
- Alignment horizontal curvature;
- Sleepers
  - –Type,
  - –Size, and
  - –Plating;
- Fasteners
  - –Type, and
  - –Defective percentage;
- Creep
  - –Rail, and
  - –Track;
- Support (local sleeper support); and
- Formation deficiencies.

Much of the data required from the field inspection is common from year to year, unless track upgrading has been undertaken, and typically 10 km/day of track can be inspected by a track supervisor.

The Track Condition Report was specifically designed to require minimum input by field staff. It is apparent from field trials that the key to acceptance and successful implementation lies in simplicity and in collecting only the minimum amount of data necessary.

In a trial of the rating system in Western Australia in one district in the summer of 1987–1988, of the 18 locations where track buckling was predicted from the rating, it occurred at 15 locations before remedial work could be undertaken.

TRACK Buckling Model

The AAR finite element track buckling model was developed by researchers at Clemson University to perform a nonlinear lateral deformation analysis on a railway track (*4*).

The program is general and takes into account

- Arbitrary rail properties, with the condition that both rails have the same properties;
- Arbitrary initial geometric imperfections;
- Rail to sleeper fastener torsional resistance, either linear or nonlinear;
- Lateral and longitudinal ballast resistance, either linear or nonlinear; and
- Arbitrary sleeper properties.

The program is capable of calculating postbuckling track deformations caused by thermal and mechanical loads and is capable of modeling tangent and curved track, including varying curvature, as in the case of a transition curve.

The model can be used to assess the adequacy of any given design track standard for resistance to buckling. The model's output was verified for a number of track structures through a parametric analysis and detailed examination of buckling statistics in Australia. Subsequently, the model was used to verify the track condition rating for a number of selected cases. However, further refinement of the assigned track stability rating would be necessary for gages other than 1067 mm.

NEUTRAL STRESS-FREE TEMPERATURE

As part of the Railways of Australia project, existing theoretical and experimental research work undertaken throughout the world was reviewed. Of particular note was the work of Whittingham (*5*), in which rail temperatures were recorded at hourly intervals over a 15-month period in Brisbane, Australia. From these data and Australian meteorological information for extreme maximum and minimum air temperatures, isotherms for expected maximum and minimum rail temperatures throughout Australia were established. Figures 2 and 3 represent the findings, from which a region's average rail temperature can be derived.

These figures form the basis of the project's neutral temperature recommendations on a regional basis throughout Australia. Neither the frequency distribution of maximum and minimum rail temperatures nor the local conditions are shown in Figures 2 and 3, but these factors need to be taken into account in the establishment of any region's design neutral rail temperature. The weighting of the design neutral temperature to a level greater than the region's mean rail temperature is recommended to reduce the probability of track buckling.

THEORETICAL ASPECTS

Safe Operating Temperatures

Central to the understanding of track buckling is the prediction of the critical buckling temperature for any particular design track structure or for a track structure with reduced buckling resistance resulting from normal in-service attrition.

Figure 4 shows the form of the typical temperature displacement curves for the buckling of a track structure and represents reduced track resistance for Curves 1 to 4. Parameters affecting the shape of the curves include curvature, alignment error, rail size, track stiffness, ballast resistance, and vehicle parameters. The dynamic margin of safety (DMS), as defined by Kish (*6*), represents the energy barrier on the temperature displacement curve that must be overcome before the track structure will buckle. The DMS against buckling equals the difference between the temperature increase above the neutral temperature to cause buckling (dT_B) and the safe temperature increase minima (dT_S). Figures 5 and 6 represent

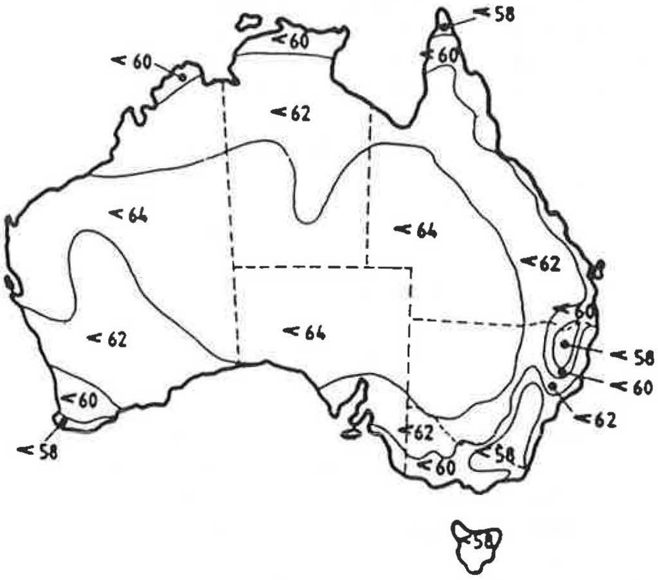

FIGURE 2 Maximum expected rail temperatures.

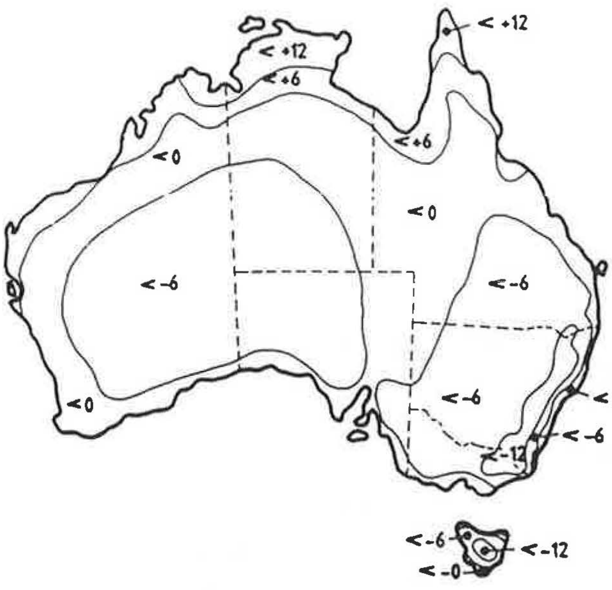

FIGURE 3 Minimum expected rail temperatures.

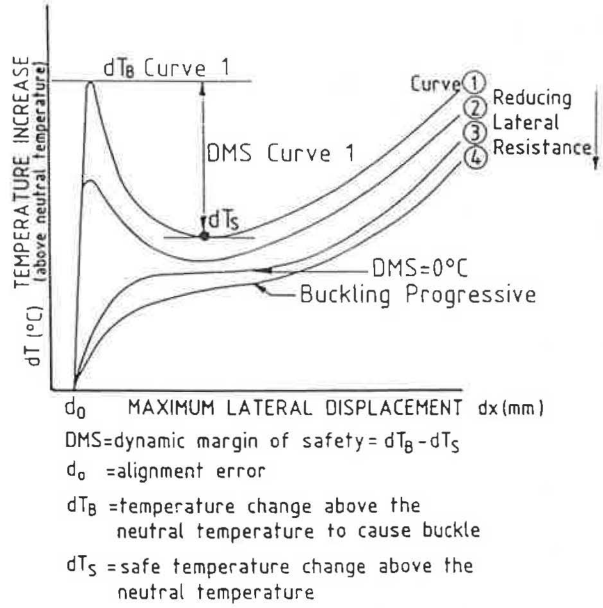

FIGURE 4 Typical temperature displacement curves.

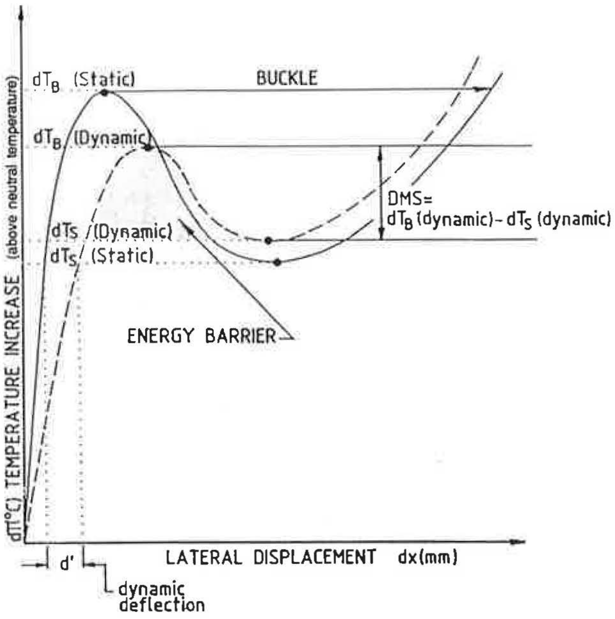

FIGURE 5 Buckling response for track with high buckling resistance.

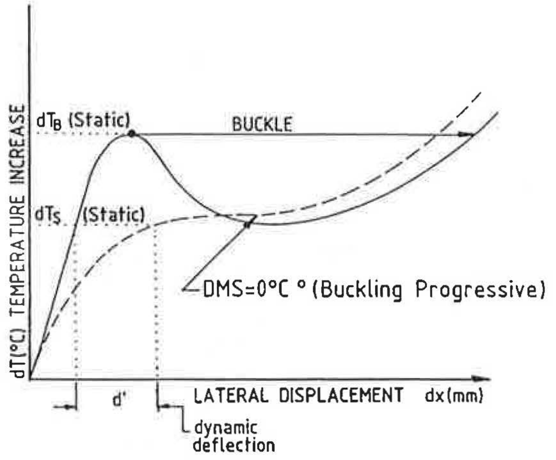

FIGURE 6 Buckling response for track with low buckling resistance.

the static and dynamic buckling responses for track structures with high and low resistance to buckling, respectively.

A track structure will buckle when the temperature exceeds the buckling temperature:

$$T_B = T_N + dT_B \tag{1}$$

where

T_B = buckling temperature,
T_N = actual neutral temperature, and
dT_B = the temperature increase above the actual neutral temperature to cause buckling.

The adequacy of any design track structure can be assessed by determining the dT_B and dT_S limits from an analytical model such as TRACK. The track's safe operating temperature (T_o) can be determined from these values. Comparison can then be made with a desired limit based on regional ambient conditions.

The following limits are recommended for the safe operating temperature T_o, based on the work of Kish (*6*) and the project findings:

When DMS ≥ 10°C,

$$T_o = T_N + dT_S \tag{2}$$

when DMS ≤ 10°C,

$$T_o = T_N + dT_B - 10°\text{C} \tag{3}$$

where

DMS = dynamic margin of safety = $dT_B - dT_S$,
T_o = safe operating temperature, and
dT_S = safe temperature increase above the actual neutral temperature.

These recommendations are represented in Figure 7. The 10°C margin that allows for dynamic loading and reduced lateral resistance following maintenance can be increased to take into account the reduced lateral stability of a track structure from the design standard due to attrition. The margin also allows for actual in-track neutral temperature variations from the design neutral rail temperature.

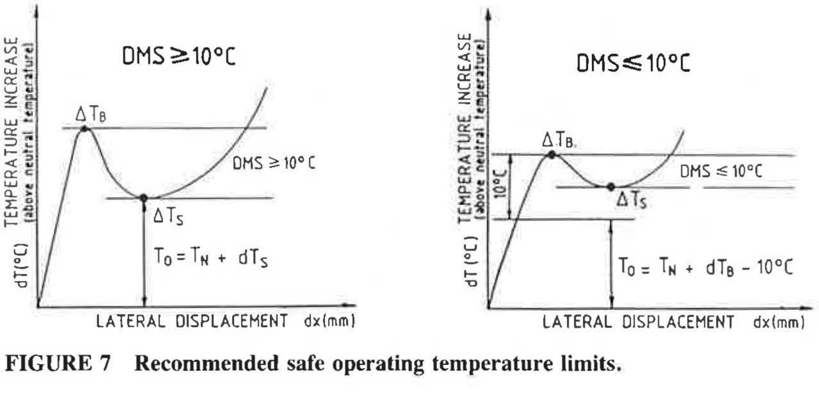

FIGURE 7 Recommended safe operating temperature limits.

Analytical Examination of Track Standards Using TRACK

The adequacy of any design track standard for stability in track buckling can be assessed using an analytical model such as TRACK. The process of assessment of existing track standards is a key element of the track buckling prevention system. The TRACK program was verified as suitable through examination of data on actual track buckling occurrences and by conducting a number of analyses of selected track standards using the program. In addition, parametric studies using TRACK were undertaken to examine a number of track standards.

It was found in the use of the analytical model of track stability that particular care was required in the analysis of the derived data and particular attention placed on selecting appropriate initial track misalignment values for dynamic deflection.

Summarized in Table 1 are the results of one of the parametric studies for the effect of rail size on a track standard's critical and safe buckling temperatures. These results are shown in Figures 8, 9, and 10 for concrete, steel, and timber sleepered track structures.

The track's safe operating temperature (T_o) has been calculated on the basis of a neutral temperature (T_N) of 35°C; however, alternative values can be substituted in Equations 2 and 3.

The effect of varying track gage for concrete sleepered track with a constant ballast profile and rail size is shown in Figure 11 for initial track misalignments of 10 and 45 mm.

TABLE 1 EFFECT OF RAIL SIZE ON CRITICAL AND SAFE BUCKLING TEMPERATURES

Concrete Sleepered Track (280 kg mass at 685 mm spacing)

Temperature (Change) ^oC		dT_B		dT_S		DMS		dT_o		T_o (dT_o + 35^{o}C)	
Initial Misalignment mm		45	10	45	10	45	10	45	10	45	10
Rail Size kg/m	20	68.1	120	58.9	120	9.2	-	58.1	-	93.1	-
	31	55.1	120	52.9	120	2.2	-	45.1	-	80.1	-
	41	48.5	103.8	48.5	60.4	0	43.4	38.5	60.4	73.5	95.4
	47	45.9	96.7	45.9	58.4	0	38.3	35.9	58.4	70.9	93.4
	50	42.4	89.0	42.4	54.0	0	35.0	32.4	54.0	67.4	89.0
	53	44.5	93.9	44.5	59.9	0	34.0	34.5	59.9	69.5	94.9
	60	48.1	89.2	48.1	58.2	0	31.0	38.1	58.2	73.1	93.2

Steel Sleepered Track (7.5 mm thick section at 685 mm spacing)

Temperature (Change) ^oC		dT_B		dT_S		DMS		dT_o		T_o (dT_o + 35^{o}C)	
Initial Misalignment mm		45	10	45	10	45	10	45	10	45	10
Rail Size kg/m	20	53.7	120	50.3	120	3.4	-	43.7	-	78.7	-
	31	44.8	98.0	44.8	57.3	0	40.7	34.8	57.3	69.8	92.3
	41	39.6	83.9	39.6	51.7	0	32.2	29.6	51.7	64.6	86.7
	47	37.9	78.8	37.9	51.4	0	27.4	27.9	51.4	62.9	86.4
	50	35.1	72.3	35.1	48.3	0	24.0	25.1	48.3	60.1	83.3
	53	40.8	76.9	40.8	50.9	0	26.0	30.8	50.9	65.8	85.9
	60	37.7	69.2	37.7	46.3	0	22.9	27.7	46.3	62.7	81.3

Timber Sleepered Track (115 x 230 x 2150 mm at 685 mm spacing)

Temperature (Change) ^oC		dT_B		dT_S		DMS		dT_o		T_o (dT_o + 35^{o}C)	
Initial Misalignment mm		45	10	45	10	45	10	45	10	45	10
Rail Size kg/m	20	48.0	105.7	45.8	55.6	2.2	50.1	38.0	55.6	73.0	90.6
	31	40.8	87.3	40.8	51.8	0	35.5	30.8	51.8	65.8	86.8
	41	37.3	76.3	37.3	48.9	0	27.4	27.3	48.9	62.3	83.9
	47	36.3	71.8	36.3	47.9	0	23.9	26.3	47.9	61.3	82.9
	50	32.6	66.2	32.6	44.8	0	21.4	22.6	44.8	57.6	79.8
	53	37.1	70.4	37.1	46.7	0	23.7	27.1	46.7	62.1	81.7
	60	34.2	63.6	34.2	43.8	0	19.8	24.2	43.8	59.2	78.8

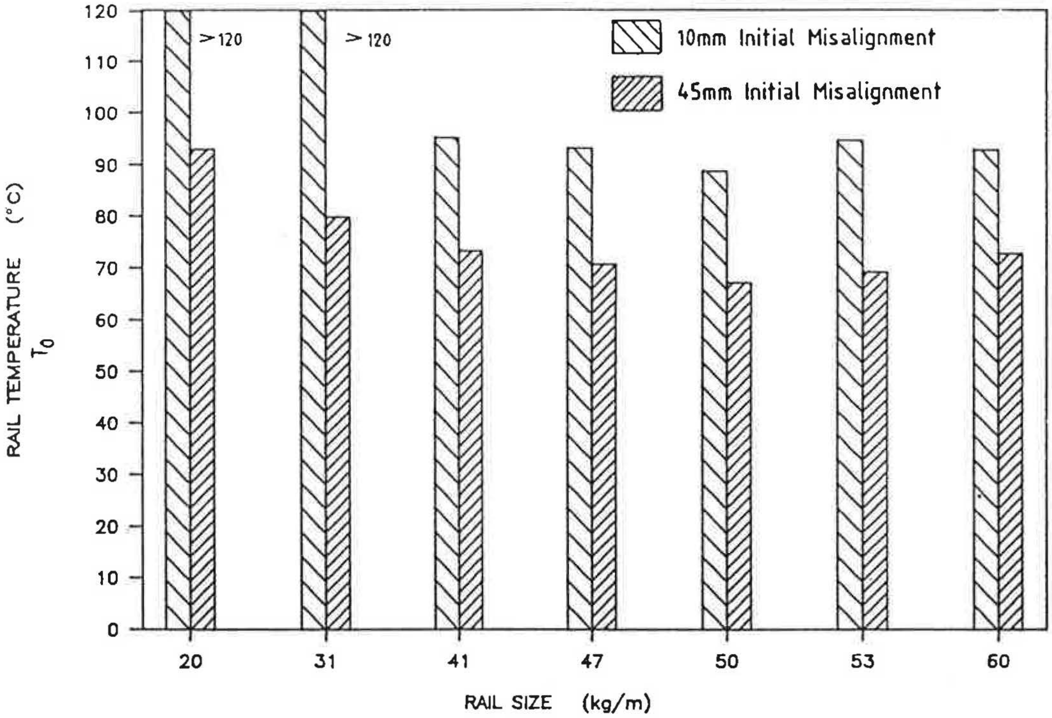

FIGURE 8 Effect of rail size on safe operating temperature—concrete sleepered track.

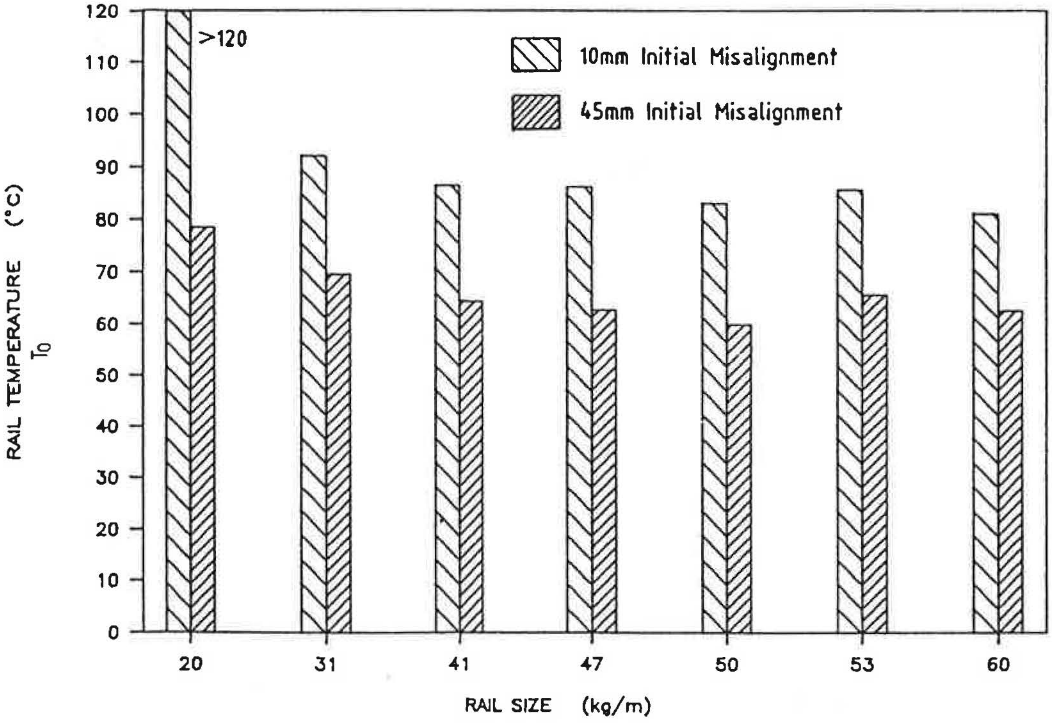

FIGURE 9 Effect of rail size on safe operating temperature—steel sleepered track.

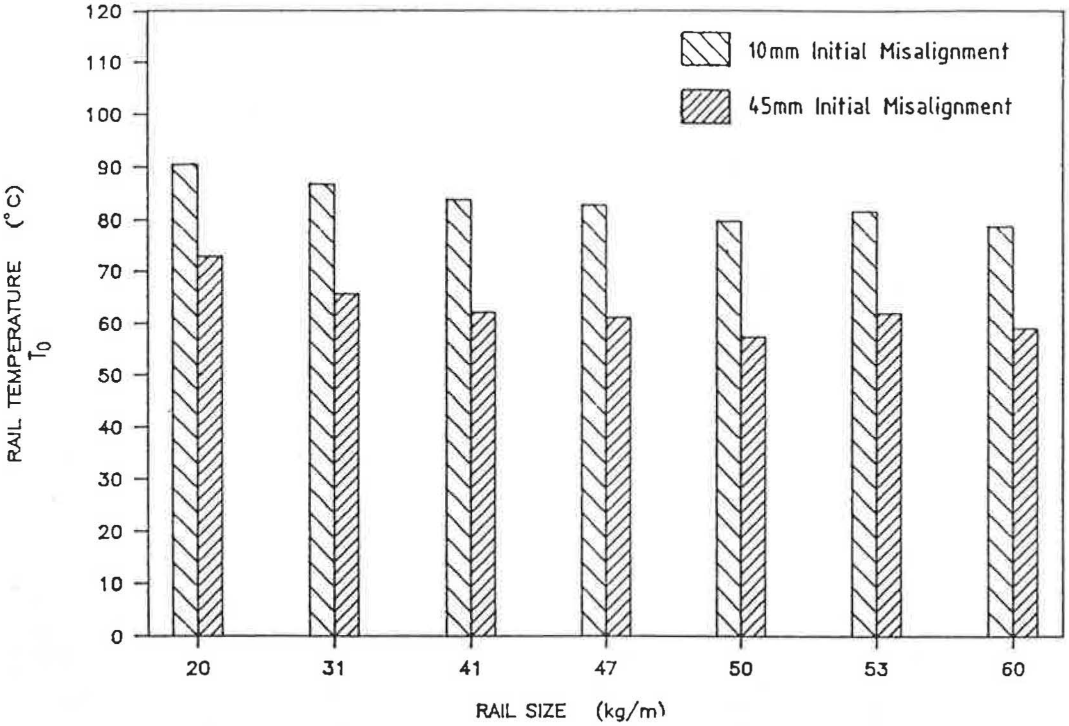

FIGURE 10 Effect of rail size on safe operating temperature—timber sleepered track.

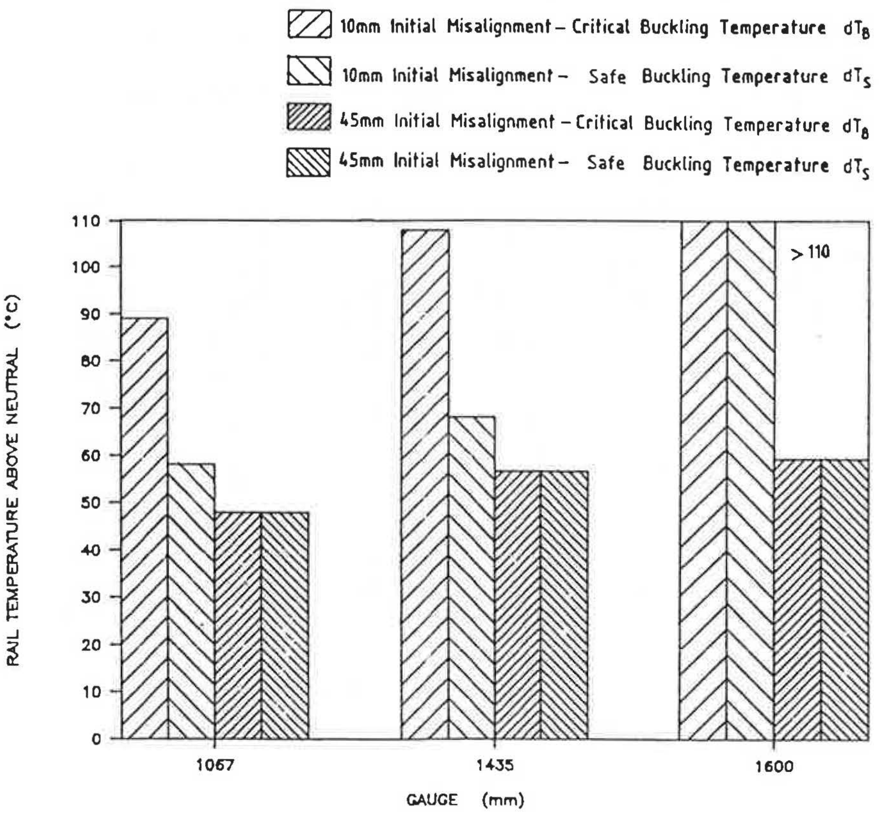

FIGURE 11 Effect of track gage on critical buckling temperature—concrete sleepered track.

POSTPROJECT ANALYSIS

Examination of the statistical data collected during the project and during the last 10 years in Queensland can give some insight into the effectiveness of increased emphasis on preemptive maintenance measures to combat buckling.

Figures 12 and 13 clearly show when the trackman must be most vigilant to detect occurrences. It is axiomatic that the greatest amount of buckling occurs in the summer, but the bias in the transition period from the cooler months and the mid-afternoon period confirms the practical experience of trackmen in Queensland.

Figure 14 shows the annual number of buckling occurrences in the Toowoomba District of southwest Queensland and demonstrates the effect of introducing mechanized maintenance procedures with a corresponding reduction in maintenance staff and the more frequent disturbance of the track and without the adoption of higher track standards or buckling prevention measures.

The measure of any project is whether it produces the required result. A clear reduction in the number of occurrences at the commencement of the project, even before significant feedback to field staff was affected, is demonstrated in Figure 15. It is clear that the increased emphasis that was placed on

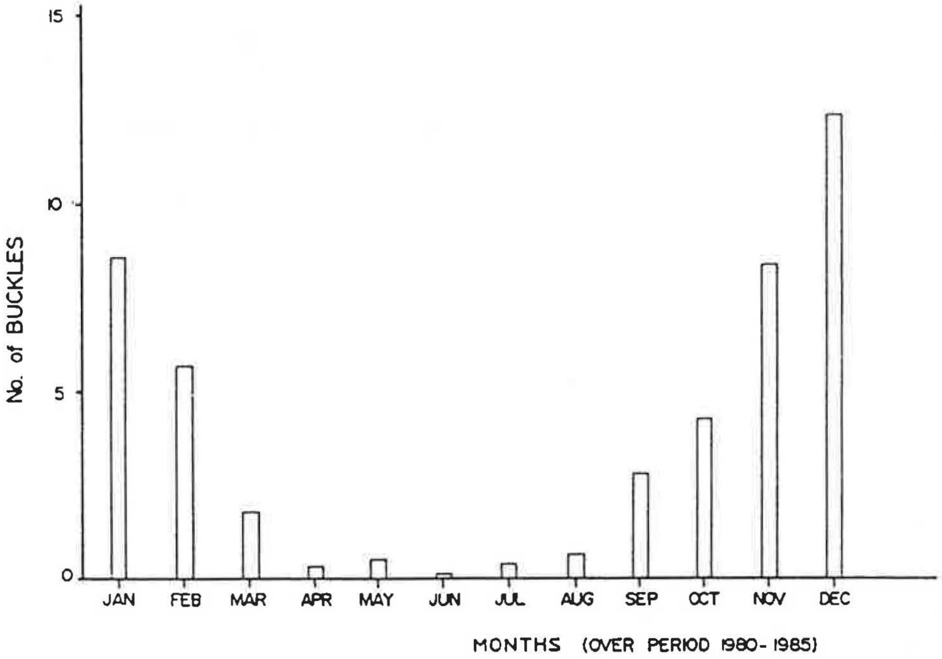

FIGURE 12 Distribution by month of track buckling in Queensland, 1980–1985.

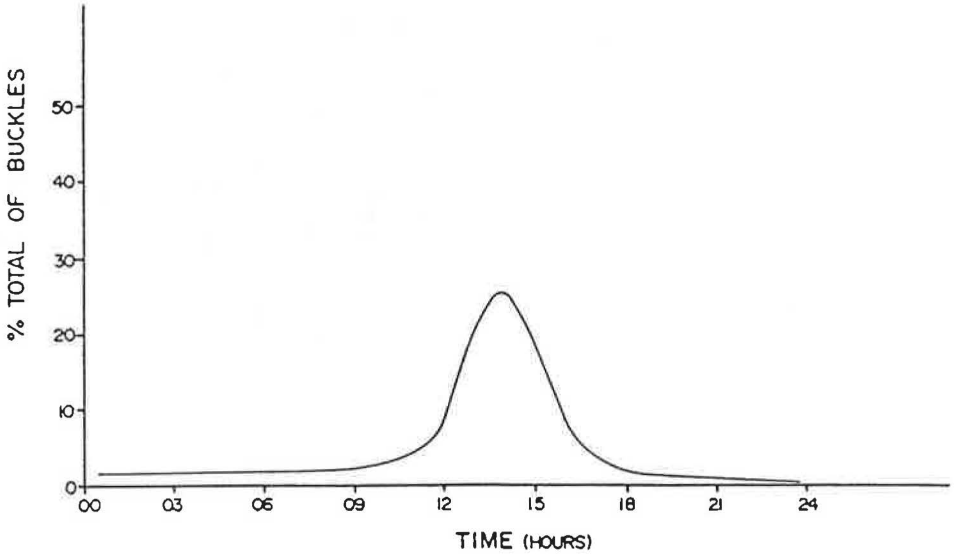

FIGURE 13 Time of occurrence of track buckling.

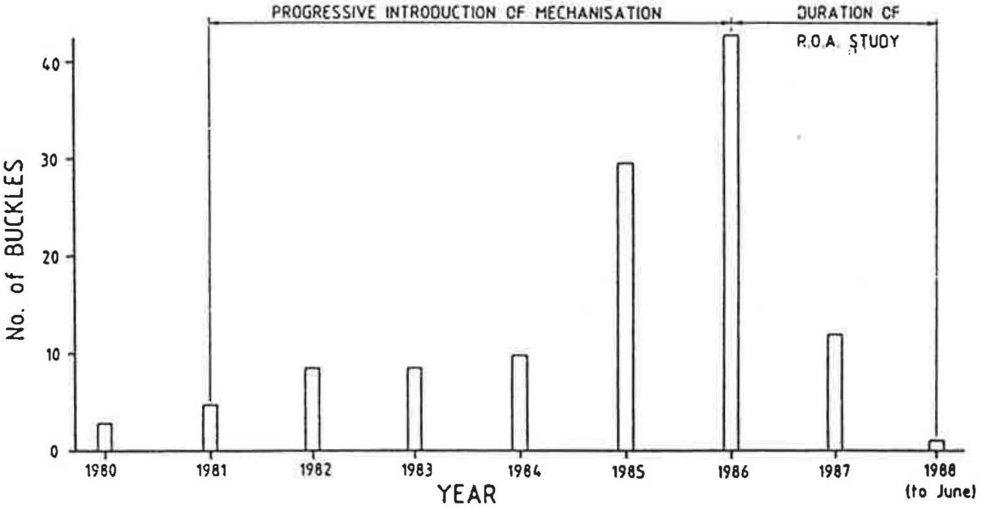

FIGURE 14 Annual distribution of track buckling in mechanized area in Toowoomba District.

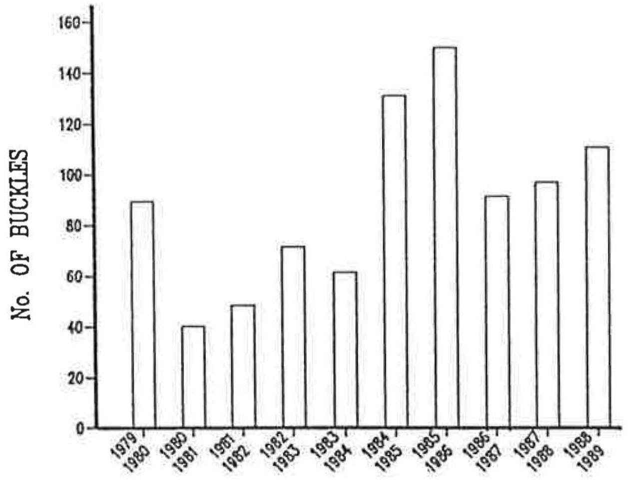

FIGURE 15 Annual track buckling occurrences in Queensland.

reducing buckling through the application of sound maintenance practices and the appropriate programming of work was a key factor.

CONCLUSION

An effective track buckling prevention system has been developed by the Queensland Railways on behalf of the Railways of Australia. The system enables a railway system to reduce the probability of track buckling on its line sections through an assessment of existing track standards, the adoption of maintenance guidelines, an annual track rating (if necessary), and the direction of maintenance resources to those areas identified as requiring urgent attention. Preemptive maintenance rather than proactive rectification was the underlying philosophy.

ACKNOWLEDGMENTS

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