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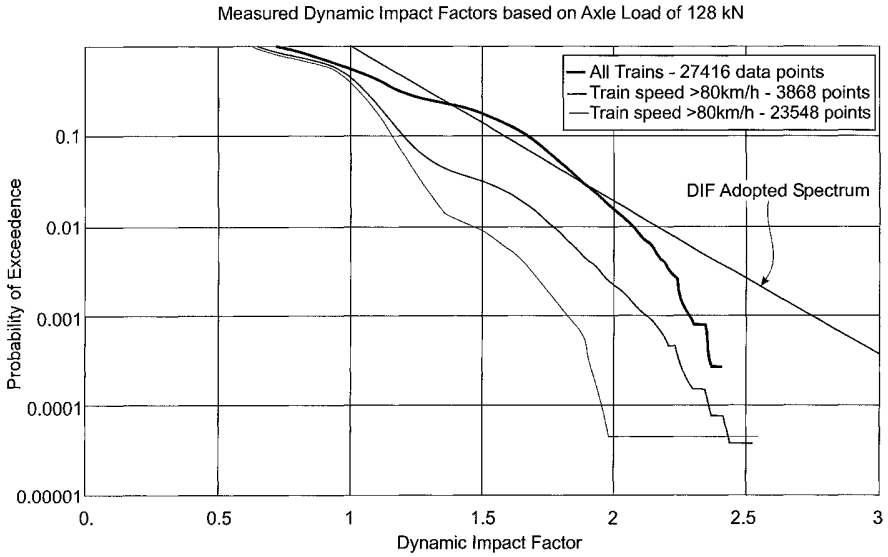
(54) Title: A METHOD OF DESIGNING A CONCRETE RAILWAY SLEEPER



(57) Abstract: A method of designing a concrete sleeper, the method including the steps of determining a loading spectrum for a length of railway track; choosing a trial sleeper design having known structural properties including bending capacity at a rail seat and the tendon and concrete stresses for a range of bending moments; determining a load distribution for the railway track including calculating a bending moment in the sleeper for a predetermined load at a known distance from the sleeper; calculating an ultimate load based on the loading spectrum; comparing the ultimate load with the bending capacity at the rail seat for the sleeper; determining fatigue life of the sleeper based on the loading spectrum, load distribution, and tendon and concrete stresses; comparing the calculated fatigue life of the sleeper with predetermined safe fatigue life values.

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"A METHOD OF DESIGNING A CONCRETE RAILWAY SLEEPER"

FIELD OF THE INVENTION

This invention relates to a method of designing a concrete railway sleeper. In particular, the invention relates to a method of designing a concrete railway sleeper for replacing existing timber sleepers on an existing railway track. However, it should be appreciated that the sleepers to be replaced may be of other material such as steel.

BACKGROUND OF THE INVENTION

Many existing railway tracks utilise timber sleepers to support the rails of a railway track. Due to a number of factors including cost and life span, timber sleepers are being used less and less in the production of railway track. As the timber railway sleepers are deteriorating with age, they need to be replaced. It would be advantageous to replace these timber sleepers with concrete sleepers due to the cost and life span of concrete sleepers. Further, replacing timber sleepers with new timber sleepers is not environmentally friendly.

In Australia and other countries around the world, engineering codes have been developed that are used to design concrete sleepers. Concrete sleepers that have similar dimensions as timber sleepers cannot be designed to satisfy these codes. That is, it is not possible to achieve the required cracking strength specified by the codes with the reduced cross section necessary to replace the timber sleepers.

OBJECT OF THE INVENTION

It is an object of the invention to overcome or alleviate the above disadvantages or provide the consumer with a useful or commercial choice.

SUMMARY OF THE INVENTION

In one form the invention resides in a method of designing a concrete sleeper, the method including the steps of:

determining a loading spectrum for a length of railway track;

choosing a trial sleeper design having known structural properties including bending capacity at a rail seat and the tendon and concrete

stresses for a range of bending moments;

determining a load distribution for the railway track including calculating a bending moment in the sleeper for a predetermined load at a known distance from the sleeper;

calculating an ultimate load based on the loading spectrum;

comparing the ultimate load with the bending capacity at the rail seat for the sleeper;

determining fatigue life of the sleeper based on the loading spectrum, load distribution, and tendon and concrete stresses;

comparing the calculated fatigue life of the sleeper with predetermined safe fatigue life values.

The loading spectrum may be obtained by measuring a multiplicity of discrete loads at a typical location on the railway track.

Dynamic impact factors may be calculated from the measured discrete loads when comparing the measured loads with a predetermined notional load. Usually, the loads are wheel or axle loads.

The probability of exceedence of any load may be calculated from the measured discrete loads.

The loading spectrum may be obtained by plotting the probability of exceedence Vs the dynamic impact factors and drawing a curve which represents an upper boundary for the plot. The loading spectrum may be represented by a straight line.

The loading spectrum may also be obtained by taking previous measurements from another railway track and applying them to a similar railway track.

The choice of trial sleeper design is normally based on the structural properties of the sleeper. Usually, a cost efficient sleeper design with the high resistance to stress within the dimensional constraints is selected.

The bending capacity at a rail seat and the tendon and concrete stresses for a range of bending moments may be calculated using standard engineering methods. Normally, the stress is calculated for bending moments at regular intervals from 0 to the ultimate bending

capacity.

The load distribution may be obtained through the use of finite element analysis. Alternatively, the load distribution may be interpolated from previous finite element analyses.

The ultimate load may be obtained by calculating an ultimate dynamic impact factor for a predetermined probability of exceedence over the life of the sleeper. The usual predetermined probability of exceedence for ultimate loads is 5% over the life of the sleeper.

Usually, the fatigue life of the sleeper takes into consideration a group of axles. Typically, the group of axles consists of two axles on a bogie at one end of the vehicle followed by two axles on a bogie at the start of the next vehicle.

The fatigue life of the sleeper is usually determined using the loading spectrum. The entire range of dynamic impact factors is normally considered i.e. 1 to the ultimate. The dynamic impact factors may be divided into a number of intervals to calculate a fraction of the fatigue life for each of the intervals.

The fraction of the fatigue life also may be calculated differently between high loads and low loads. The high loads may be considered in the top 25% whilst the low loads may be in the bottom 75%.

BRIEF DESCRIPTION OF THE DRAWINGS

An example of the method will be described with reference to the accompanying drawings in which:

FIG. 1 is a graph of the probability of exceedence Vs measured dynamic impact factors (DIF);

FIG. 2 is a graph showing the straight line representing the loading spectrum;

FIG. 3 is a table representing sleeper properties for a trial sleeper design designated as “Low Profile Sleeper, 260 Wide 866 Strand”;

FIG. 4 is a diagram representing the bending moment in a sleeper as a single load passes over it;

FIG. 5 is a load distribution diagram showing the bending moments in a sleeper due to the passage of a group of adjacent axles;

FIG. 6 shows the bending moments a sleeper might be subjected to for CASE A;

FIG. 7 shows the bending moments a sleeper might be subjected to for CASE B;

FIG. 8 is a diagram of the stress ranges that might correspond to the bending moment ranges of FIG. 6;

FIG. 9 is a diagram of the moments used to calculate the stress ranges for the lower 75% of loads;

FIG. 10 is a diagram representing the fraction of a load carried by a sleeper, at a distance from the load; and

FIGS. 11A to 11F represent a table of fatigue results for the intervals between DIF = 1 and the DIF = ultimate.

DETAILED DESCRIPTION OF THE PREFFERED EMBODIMENT

An embodiment, by way of example only, of a method of designing a sleeper is described below.

The sleeper that is to be designed must cater for the following design criteria.

DESIGN CRITERIA

Rail Construction

Gauge:	Broad
Sleeper Width:	260
Sleeper Depth:	130, 140 at rail seat
Rail Size:	50 kg
Sleeper Spacing:	670

Rollingstock:

Nominal Axle Load (P_A):	128 kN
Axle spacing on bogie (b):	2.6m
Axle spacing over Coupler (c):	5.3m
Axles/Car:	4
Cars/Train:	5
Trains per year:	36000
Design life (years):	50
Total number of load cycles	= 36000 x 5 x 4 x 50

$= 36 \times 10^6$

LOADING SPECTRUM

Measurements of actual wheel loads from trains were taken over a period of time at a typical location on the railway track for which the sleepers are to be designed. These measurements were then used to calculate a range of dynamic impact factors (DIF) using the follow formula:

DIF = Measured Wheel Load/Nominal Wheel Load

Hence, the dynamic impact factor (DIF) is applied to the nominal wheel or axle load to get the actual wheel or axle load.

The probability of a measured dynamic impact factor exceeding any particular dynamic impact factor was also calculated from measured loads.

The probability of exceedence Vs the dynamic impact factors was then plotted on a graph show in FIG. 1. A line representing a conservative analysis of the probability of exceedence Vs the dynamic impact factors was then drawn to represent the loading spectrum.

Referring to FIG. 2 (a simplified version of the loading spectrum of FIG. 1), the loading spectrum is represented by the straight line which approximates the test results. These are plotted as log (þ) Vs DIF where þ is the probability of exceedence and DIF is the Dynamic Impact Factor. The straight line is defined by the constant A and B which can be determined from DIF_1 which gives þ of 1.0, and $DIF_{.001}$ which gives a þ of 0.001.

Accordingly we have

$$\text{Log}(þ) = A.DIF + B$$

$$\Rightarrow \quad þ = 10^{(A.DIF + B)}$$

To find the number of cycles in a range from DIF_i to DIF_j:

$$n_{ij} = (þ(DIF_j) - þ(DIF_i)) \times n_T$$

where n_T is the total number of cycles.

SLEEPER PROPERTIES

A sleeper design is then chosen that is thought to have suitable stress and bending moment properties. These properties are usually calculated using cross-section response software that is readily

available to a person skilled in the art.

For this example, FIG. 3 shows a table indicating tendon stress and concrete stress at various bending moments of the trial concrete sleeper design (Low Profile Sleeper 260 wide, 866 Strands) that was thought to have suitable properties to satisfy the design requirements. In particular bending capacity at a rail seat of the sleeper and the maximum tendon stresses and concrete stresses for a range of bending moments between 0 and ultimate were determined. Also the reliable ultimate bending capacity (ΦM_u) was calculated to be 22.6 kNm.

LOAD DISTRIBUTION

The rail construction controls the load distribution. That is, the bending moment each sleeper sees when an axle of a known load passes over it.

If the moment in the sleeper immediately below the load (M_o) is known, as well as what fraction of the total load is carried by that sleeper (DF_o), then the curve, shown in FIG. 4, can be approximated by assuming the curve shape is similar to that obtained from a classical beam on elastic foundation solution.

Hence, using finite element analysis for this rail construction, the following results were obtained for a nominal load of P_o = 100 kN (wheel load):

M_o = 5.36 kNm

DF_o = 0.469

The values for M_o and DF_o are determined by a finite element analysis. However, it should be appreciated that as solutions for more track configurations are obtained it will be possible to interpolate values for M_o and DF_o from previous solutions.

CHECK ULTIMATE LOAD

The ultimate load is defined as having a probability of exceedence of 5% over the life of the sleeper.

Hence, if β_{ult} is the probability of exceedence of the ultimate load in one cycle (as yet unknown) and n is the number of cycles in the sleeper design life,

then

$$0.05 = 1 - (1 - \rho_{ult})^n$$

which gives

$$\rho_{ult} = 1.0 - 0.95^{(1/n)}$$

when ρ_{ult} is known, the load spectrum can be used to find the ultimate Dynamic Impact Factor (DIF_{ult}) which has a probability of exceedence of ρ_{ult}. This is applied to the nominal wheel load to give the ultimate wheel load.

For the above example:

$$n = 36 \times 10^6$$

$$\rho_{ult} = 1.0\text{-}0.95^{(1/36\times10^6)}$$

$$= 1.425 \times 10^{-9}$$

Load spectrum:

$$\text{Log}(\rho) = A.DIF + B$$

$$DIF_{ult} = \frac{\log(\rho_{ult}) - B}{A} = 6.160$$

Hence, ultimate axle load:

$$P_{ult} = 6.16P$$

where

$$P = \text{nominal wheel load}$$

$$= 0.5\, P_A$$

$$= 64 \text{ kN}$$

Hence:

$$P_{ult} = 6.16 \times 64 \text{ kN}$$

$$= 394 \text{ kN}$$

Ultimate bending moment at rail seat:

$$M_{ult} = M_o \times \frac{P_{ult}}{P_o}$$

$$= 5.36 \times \frac{394}{100}$$

$$M_{ult} = 21.1 \text{ kNm}$$

Sleeper bending capacity at rail seat (from sleeper properties)

$$= 22.6 \text{ kNm}$$

Therefore, the sleeper that has been chosen will withstand the theoretical ultimate bending moment.

FATIGUE ASSESSMENT

The bending moment and stress ranges in a sleeper due to the passage of a group of axles (consisting of two axles on a bogie at the end of one vehicle followed by two axles on a bogie at the start of the next vehicle) is considered. This is because these axles are generally close enough together so that a sleeper receives load from more than one axle. A representation of this is shown in FIG. 5.

The loads applied to a sleeper range vary widely according to the dynamic impact spectrum. The distribution of the very high loads among the lower loads will also affect the fatigue life.

Consider the following two cases:

Each case has 4 axle groups (each with 4 axles), 4 very high loads, and 12 lower loads.

CASE A. One very high load/axle group as shown in FIG. 6

CASE B. Four very high loads in one group, and four lower loads in three more groups show in FIG. 7.

The fatigue damage due to a cycle of load stress is proportional to the load range raised to some power,

i.e. Damage = $K\Delta M^m$

m varies according to the material. As a minimum m = 3, but is often much higher. Hence a large load range can do much more damage than many smaller ranges. It is likely that Case A above will result in more fatigue damage than Case B. To investigate this, assume some relative magnitudes for the moment ranges shown in FIG. 6 and FIG. 7.

Let $\Delta M_E = 2 \Delta M_n$

$\Delta M_{BE} = 0.5 \Delta M_E$, $\Delta M_{BN} = .5 \Delta M_N$

$\Delta M_{CE} = 0.6 \Delta M_C$, $\Delta M_{CN} = .6 \Delta M_N$

The damage due to N_a cycles of ΔM_a, say, can be expressed as a number of cycles N_E of M_a which will cause equivalent fatigue damage:

$N_a \Delta M_a^m = N_E \Delta M_E^m$

$$N_E = N_a\left(\frac{\Delta M_a}{\Delta M_E}\right)^m$$

For Case A, express the total damage as an equivalent number of cycles of ΔM_E. Use m=3.

Cycles	Range	Equiv. Cycles of ΔM_E	
4	ΔM_E	**4**	
8	ΔM_{EN}	**.125**	**$8 \times (.25)^3$**
4	ΔM_{CN}	**.108**	**$4 \times (0.30)^3$**
	Total Equivalent Cycles:	**4.233**	

Similarly for Case B

#Cycles	**Range**	**Equiv. Cycles of ΔM_E**	
1	ΔM_E	1.0	
2	ΔM_{BN}	.25	$2 X .5^3$
1	ΔM_{CN}	.216	$1 X .6^3$
3	ΔM_N	.375	$3 X .5^3$
6	ΔM_{BN}	.094	$6 X .25^3$
3	ΔM_{CN}	0.81	$3 X .3^3$
	Total Equivalent Cycles:	2.016	

Clearly, Case A results in more fatigue damage (4.23 cycles of ΔM_E) than Case B (2.02 cycles of ΔM_E).

Hence, as a worst case, it is assumed that the highest 25% of the loads in the spectrum are distributed so that there is one in each axle group. The other 3 axles in each group are drawn from the lower 75% of the loads in the spectrum. This stress range is represented by FIG. 8.

Hence, for the upper 25% of the loads, the full stress cycle (Δf_{full}) is considered. For the lower 75% of the loads the stress range between wheels on a bogie (Δf_b) is considered for 2/3 of the instances, and the stress range for wheels on either side of a coupler (Δf_c) for one-third of the instances.

Note, if the axle spacing on the bogie or across the coupler

gets large, then these Δf_b and Δf_c become full cycles. In this case, a full cycle of load for each axle is effectively considered.

The bending moments in the sleeper are calculated as shown in FIG. 9. The stress range Δf_b is calculated from:

Δf_b = f due to M_1 - f due to M_b

and Δf_c = f due to M_2 – f due to M_c

The load distribution (as defined by M_o, DF_o) and the wheel spacing allow this to be achieved. To achieve this the distribution factors at various distances from a load are calculated. These give the fraction of the entire load carried by a sleeper at a distance from the load. This is represented by FIG. 10.

Hence, the moment under the first axle M_1 is

$$M_1 = \frac{DF_o + DF(b)}{DF_O} \times M_O \times \frac{P}{P_O} \times DIF$$

where DIF is the dynamic impact factor from the load spectrum.

P is the nominal wheel load = 0.5 P_A.

P_o is wheel load used in the FEA.

M_o is the sleeper moment from the FEA.

Similarly,

$$M_B = \frac{2 \times DF(b/2)}{DF_O} \times M_O \times \frac{P}{P_O} \times DIF$$

$$M_2 = \frac{\left(DF_O + DF(b) + DF(c)\right)}{DF_o} \times M_o \times \frac{P}{P_o} \times DIF$$

$$M_c = \frac{2 x DF(c/2)}{DF_o} \times M_o \times \frac{P}{P_o} \times DIF$$

For the fatigue assessment all load cycles with loads less than or equal to the ultimate load are considered. The range of dynamic impact factors considered is from 1.0 to DIF_{ULT}. The full range of DIF is subdivided into smaller ranges for assessment. The fatigue damage in each small range is calculated by assuming the mean DIF for the range applies to all of the cycles in the range. The fatigue damage for each small range is then summed together to get the total fatigue damage.

FATIGUE ASSESSMENT FOR THIS SLEEPER

The results of the fatigue assessment for this sleeper is shown in FIG. 11 with a summary of the design criteria and results shown in FIG. 12. Examples of how these fatigue results were obtained are shown below. The results of the fatigue assessment shown in the FIG. 11 were obtained in the same manner.

The range of DIF was divided into intervals. Note that the lower 75% of cycles are treated differently from the upper 25% for the reasons stated above.

$DIF_{min} = 1$

$DIF_{ult} = 6.16$

$$DIF_{75\%} = \frac{\log(0.25) - B}{A}$$

$= 1.3512$

Divide the range from 1 to 1.3512 into 5 intervals. (This is the lower 75% of all cycles.)

(1 → 1.070, 1.070 → 1.140, 1.140 → 1.211, 1.211 → 1.281, 1.281 →1.351)

Divide the range from 1.351 to 6.16 0 into 20 intervals. (This is the upper 25% of all cycles.)

(1.351 → 1.592, 1.592 → 1.832 etc)

Calculate the fatigue damage for each interval.

Example for lower 75% intervals:

Consider the range:

DIF = 1.211 to 1.281

Avg DIF for this range = 1.246.

Assume this applies to all cycles in this interval.

Number of cycles in this interval:

$n_{ij} = (þ(DIF_j) - þ(DIF_i)) \times n_T$

$= (þ(1.281) - þ(1.211)) \times n_T$

$= (10^{(Ax1.281 + B)} - 10^{(A\,1.211 + B)})n_T$

$= 3.794 \times 10^6$ cycles

Two-thirds of these cycles are subject to stress range Δf_b.

The stress range between when the first axle of a group crosses the sleeper and when the bogie is centred over the sleeper. This is equal to the stress due to M_1 less the stress due to M_b.

One-third of these cycles are subject to stress range Δf_c. The stress range between when the second axle of a group crosses the sleeper and when the coupler is centred over the sleeper. This is equal to the stress due to M_2 less the stress due to M_c.

Hence, calculate M_1

$$M_1 - \frac{DF_O + DF(b)}{DF_O} \times M_o \times \frac{P}{P_o}$$

DF_o	=	0.469
DF(b/2)	=	.0549
DF(b)	=	-.0167
$DF(c/2)$	=	-.0159
DF(c)	=	.00004
M_o	=	5.36kNm
P_o	=	100 kN
P	=	64 kN
DIF	=	DIF mean = 1.246
	$\Rightarrow$	M_1 = 4.122 kNm

Interpolate, from the table shown in FIG 3, the structural response of sleeper to get tendon stress σ, and concrete stress at the top and bottom of the sleeper (f_{ctop}, f_{cbtm}) for this moment (M_1).

We get σ_1 = 911.8 MPa

f_{ctop1} = 14.39 MPa

Similarly for M_b

M_b = 1.000 kNm

σ_b = 903.7 MPa, $f_{c\,topb}$ = 10.62 Mpa

Similarly for M_2

M_2 = 4.126 kNm

σ_2 = 911.8 MPa, f_{ctop2} = 14.39 MPa

Similarly for M_c

M_c = -0.289 kNm

σ_c = 900.3 MPa, f_{ctopc} = 9.16 MPa

Calculate the stress ranges over the bogie (Δf_b) and over the coupler (Δf_c).

Over the bogie:

For tendons

$$\Delta \sigma_b = \sigma_1 - \sigma_b = 8.1 \text{ MPa}$$

For concrete

A simple stress range is not used in assessing concrete fatigue. Record maximum and minimum stresses.

f_{cmaxb} = 14.39 MPa, f_{cminb} = 10.62 MPa

Over the coupler:

For tendons

$$\Delta \sigma_c = \sigma_2 - \sigma_c = 11.5 \text{ MPa}$$

For concrete

f_{cmaxc} = 14.39 MPa, f_{cminc} = 9.06 MPa.

Calculate the fraction of the total fatigue life of the tendons that is used up by the cycles in this DIF interval. In this example this is done using the provisions of the European code, however other codes or recognised methods could be used.

At a stress range of $\phi\Delta\sigma^*$, 1 x 10^6 cycles constitutes the full fatigue life.

Calculate the number of cycles $\phi\Delta\sigma^*$ which causes equivalent fatigue damage to:

$\frac{2}{3}$ of 3.794 x 10^6 cycles at $\Delta\sigma$ = 8.1 MPa

$\frac{1}{3}$ of 3.794 x 10^6 cycles at $\Delta\sigma$ = 11.5 MPa

For $\Delta\sigma < \Phi\Delta\sigma^*$, m = 9

N_{eq}

$$= \frac{2}{3} \times 3.794 \times 10^6 \times \left(\frac{8.11}{\phi\Delta\sigma^*}\right)^9 + \frac{1}{3} \times 3.794 \times 10^6 \times \left(\frac{11.47}{\phi\Delta\sigma^*}\right)^9$$

From the code use $\Delta\sigma^*$ = 120 for this design, and Φ = .79

Hence,

N_{eq} = .00766 cycles

The full fatigue life at $\Delta\sigma^*$ is 1 x 10^6 cycles.

Therefore, the fraction of fatigue life used this DIF interval

= 7.66 x 10^{-9}

Calculate the fraction of the total fatigue life for the concrete that is used up by the cycles in this interval.

Using the European code, concrete fatigue requirements:

Over bogie:

f_{cmax} = 14.39 MPa, f_{cmin} = 10.62 MPa

The code gives the full fatigue life for this stress range to be:

N_b = 8.1 x 10^{122} cycles

Over coupler:

f_{cmax} = 14.39 MPa, f_{cmin} = 9.06 MPa

The code gives the full fatigue life for this stress range to be:

N_c = 1.6 x 10^{153} cycles

Fraction of fatigue life used in this interval is:

$$\frac{2/3 \times 3.794 \times 10^6}{8.1 \times 10^{122}} + \frac{1/3 \times 3.794 \times 10^6}{1.6 \times 10^{158}} = 3.1 \times 10^{-117}$$

In summary, in this DIF interval 7.66 x 10^{-9} of the tendon fatigue life was used and 3.1 x 10^{-117} of the concrete fatigue life was used.

Example for upper 25% intervals

Consider the range:

DIF = 5.198 to 5.439

Avg DIF = 5.319

Number of cycles in interval = 1.400

The stress range considered for the upper 25% intervals is from the no load condition to the maximum load when the wheel is above the sleeper.

Sleeper moment when wheel above sleeper.

Total moment under peak wheel

$$M_P = M_o \times DIF \times \frac{P}{P_o} + M_o \times DIF_{75\%} \frac{DF_{(b)} + DF_{(C)}}{DF_O} \times \frac{P}{P_o}$$

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$$= (5.319 + 1.351 \times \frac{(0.0+.0004)}{0.469} \times 5.36 \times \frac{64}{100}$$

$$= \quad 18.25 \text{ kNm}$$

Hence the stress ranges are between M = 0 and M = 18.25 kNm.

Interpolate from structural response table in FIG. 3.

		M = 0	M = 18.25
Tendon	σ	901.1 MPa	1011.5 MPa
Concrete	f_{ctop}	9.41 MPa	38.74 Mpa

Hence,

$$\Delta \sigma = 110.4 \text{ MPa}$$

Calculate faction of total fatigue life used up by cycles in this interval.

Tendons

$$N_{eq} = 1.4 \times \frac{(110.4)^m}{\phi \Delta \sigma^*} \quad m = 5 \text{ since } 110.4 > \phi \Delta \sigma^*$$

$$N_{eq} = 3.00$$

Fraction of total fatigue life = $3/(1 \times 10^6) = 3 \times 10^{-6}$

Concrete

$$f_{cmax} = 38.74$$

$$f_{cmin} = 9.41$$

Code gives total life for this range as 55.06 cycles

Fraction of fatigue life for this interval is

$$\frac{1.4}{55.6} = 0.0254$$

Calculate the total fatigue damage.

The fatigue damage to the tendons and concrete in each interval is summed:

The total fraction of tendon fatigue life used is 1.9×10^{-5}.

Since this is less than 1.0 the tendons can be expected to not fail due to fatigue over the design life.

The total fraction of the concrete fatigue life used is 6.1 according to the provisions of the European code. Hence, according to this code, the concrete would fail from fatigue before reaching the end of the sleepers design life.

Alternative methods to the European code can be used to assess that fatigue life of tendons and concrete subjected to known stress ranges.

The provisions in the European code for fatigue in concrete have been found to be over conservative for low numbers of cycles at very high stresses and hence, unsuitable in their current form to this application as stress cycles up to the ultimate moment are considered.

Modifications have been made to the equations in the European code to allow higher stress ranges at low numbers of cycles. Tests have been conducted to verify that the modified provisions are safe.

When assessed according to the modified provisions of total fraction of the concrete fatigue life used is 0.036. Hence, the concrete is not expected to fail in fatigue over the design life of the sleeper.

The above method of design of a concrete sleeper provides a rational design approach for low profile concrete sleepers than may be used to replace timber sleepers. The design method considers the entire load spectrum rather than a nominal design; considers local distribution; considers fatigue in concrete and in steel; considers ultimate capacity, and considers durability. In this manner, a concrete sleeper can be designed that is unlikely to fail but meets the physical constraints.

It should be appreciated that various other changes and modifications may be made to the example described without departing from the spirit or scope of the invention.

CLAIMS:

1. A method of designing a concrete sleeper, the method including the steps of:

determining a loading spectrum for a length of railway track;

choosing a trial sleeper design having known structural properties including bending capacity at a rail seat and the tendon and concrete stresses for a range of bending moments;

determining a load distribution for the railway track including calculating a bending moment in the sleeper for a predetermined load at a known distance from the sleeper;

calculating an ultimate load based on the loading spectrum;

comparing the ultimate load with the bending capacity at the rail seat for the sleeper;

determining fatigue life of the sleeper based on the loading spectrum, load distribution, and tendon and concrete stresses;

comparing the calculated fatigue life of the sleeper with predetermined safe fatigue life values.

2 The method of claim 1 wherein the loading spectrum is obtained by measuring a multiplicity of discrete loads at a location on the railway track.

3. The method of claim 1 wherein the dynamic impact factors are calculated from the measured discrete loads when comparing the measured loads with a predetermined notional load.

4. The method of claim 1 wherein the probability of exceedence of any load is calculated from the measured discrete loads.

5. The method of claim 1 wherein the loading spectrum is obtained by plotting the probability of exceedence Vs the dynamic impact factors and drawing a curve which represents an upper boundary for the plot.

6. The method of claim 1 wherein the loading spectrum is obtained by taking previous measurements from another railway track and applying them to a similar railway track.

7. The method of claim 1 wherein the trial sleeper design is

chosen based on the structural properties of the sleeper.

8. The method of claim 7 wherein the sleeper design is chosen with the high resistance to stress within the dimensional constraints.

9. The method of claim 1 wherein the bending capacity at a rail seat and the tendon and concrete stresses for a range of bending moments is calculated using standard engineering methods.

10. The method of claim 9 wherein the stress is calculated for bending moments at regular intervals from 0 to the ultimate bending capacity.

11. The method of claim 1 wherein the load distribution is obtained through the use of finite element analysis.

12. The method of claim 1 wherein the load distribution is interpolated from previous finite element analyses.

13. The method of claim 1 wherein the ultimate load is obtained by calculating an ultimate dynamic impact factor for a predetermined probability of exceedence over the life of the sleeper.

14. The method of claim 1 wherein the fatigue life of the sleeper takes into consideration a group of axles.

15. The method of claim 14 wherein the group of axles consists of two axles on a bogie at one end of the vehicle followed by two axles on a bogie at the start of the next vehicle.

16. The method of claim 1 wherein the fatigue life of the sleeper is determined using the loading spectrum.

17. The method of claim 1 wherein the entire range of dynamic impact factors is considered.

18. The method of claim 17 wherein the dynamic impact factors are divided into a number of intervals to calculate a fraction of the fatigue life for each of the intervals.

19. The method of claim 18 wherein the fraction of the fatigue life is calculated differently between high loads and low loads.

20. The method of claim 19 wherein the high loads are considered in the top 25% whilst the low loads are in the bottom 75%.

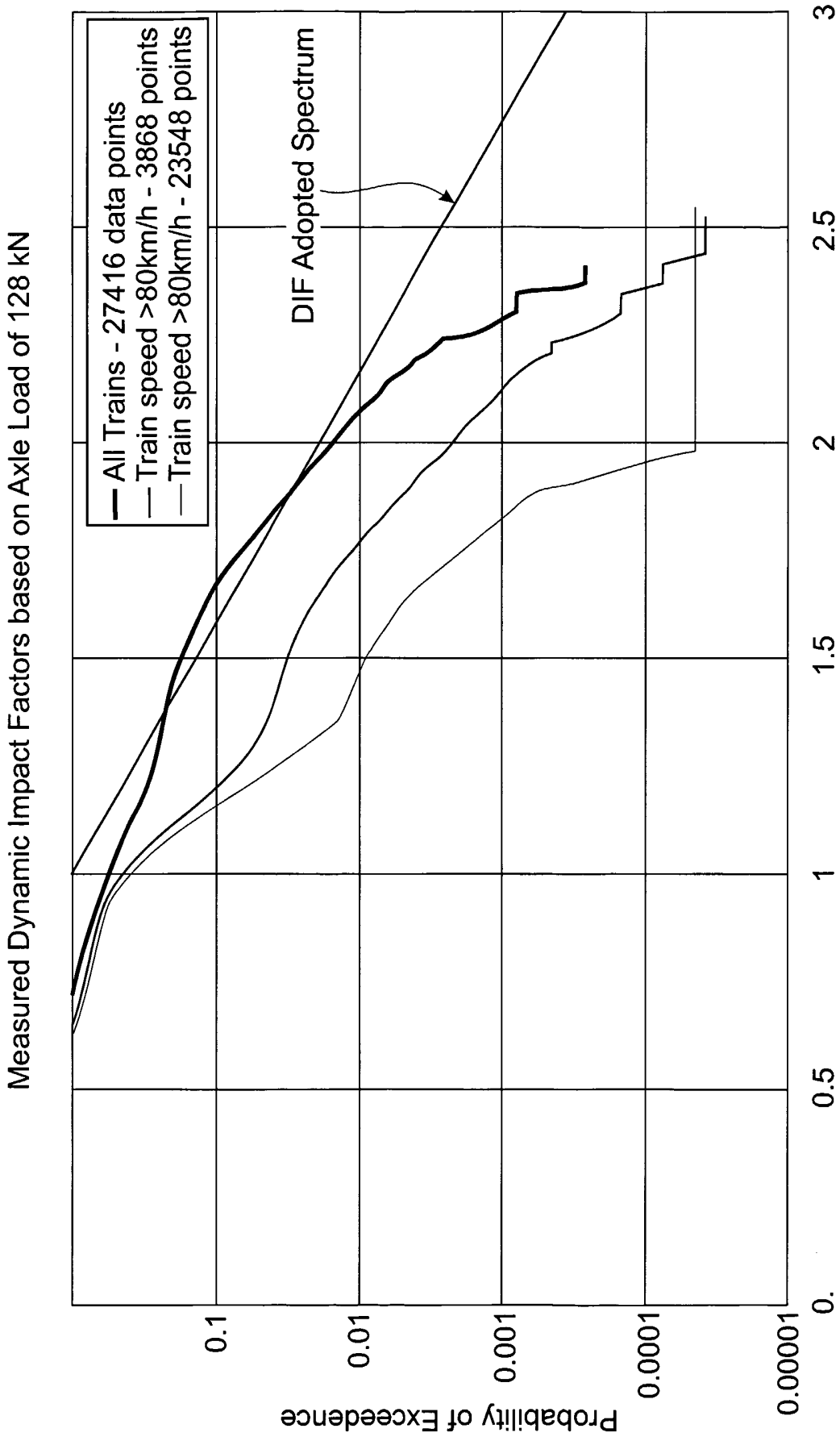

Measured Dynamic Impact Factors based on Axle Load of 128 kN
All Trains - 27416 data points
Train speed >80km/h - 3868 points
Train speed >80km/h - 23548 points
DIF Adopted Spectrum
Probability of Exceedence
0.1
0.01
0.001
0.0001
0.00001
0.
0.5
1
1.5
2
2.5
3
Dynamic Impact Factor

FIG. 1

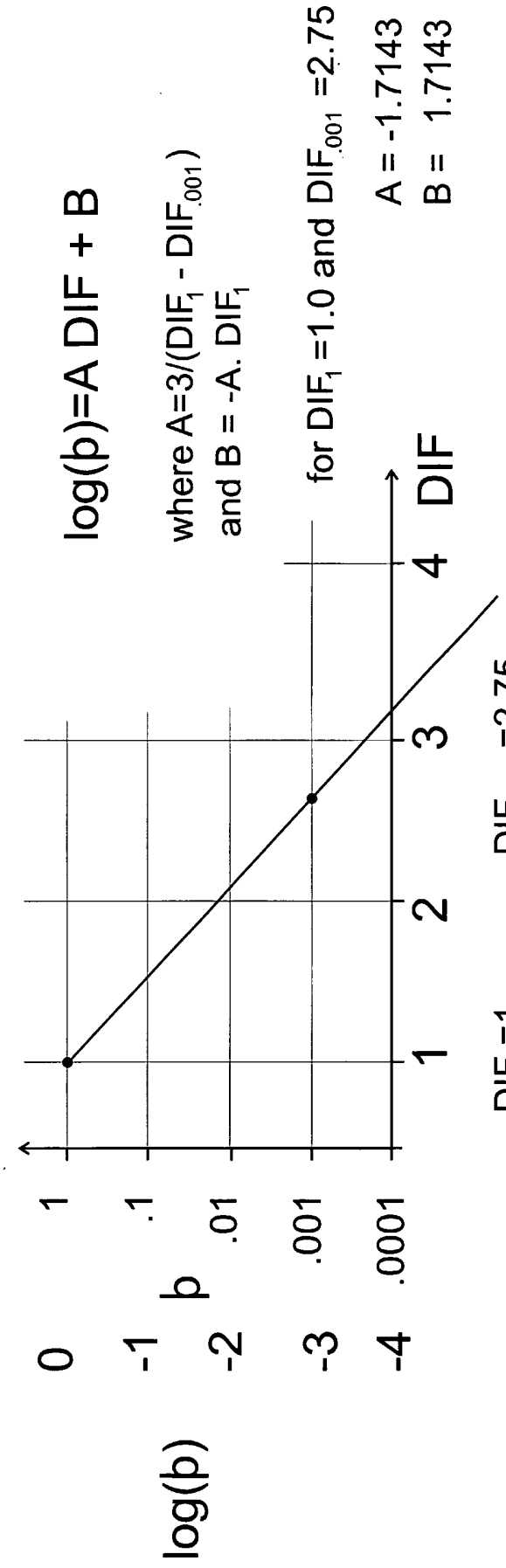

log(b)=A DIF + B
where A=3/(DIF1 - DIF.001)
and B = -A. DIF1
for DIF1 =1.0 and DIF.001 =2.75
A = -1.7143
B = 1.7143
log(b)
0
-1
-2
-3
-4
b
1
.1
.01
.001
.0001
1
2
3
4
DIF
DIF1=1
DIF.001=2.75

FIG. 2

Positive bending moment vs max tendon stress for sleeper

Moment (kNm)	Tendon Stress (MPa)	Top Conc Stress (MPa)	Btm Conc Stress (MPa)
-1	898.5	8.21	12.52
0	901.1	9.41	11.34
2	906.3	11.82	8.98
4	911.5	14.24	6.63
6	916.6	16.64	4.27
8	921.8	19.05	1.91
9	924.4	20.25	0.73
10	927	21.47	0
11	930.4	22.8	0
12	934.8	24.29	0
13	940.6	25.98	0
14	948.2	27.89	0
15	958.2	30.05	0
16	970.6	32.44	0
17	986.3	35.09	0
18	1005.7	37.99	0
19	1029.1	41.01	0
20	1056.9	44.33	0
21	1088	47.59	0
22	1122.9	50.75	0
23	1161.6	53.73	0
24	1203.2	56.32	0
25	1248.6	58.41	0
26	1298.3	59.74	0
27	1351.8	60	0
28.01	1447.6	60	0
0			

FIG. 3

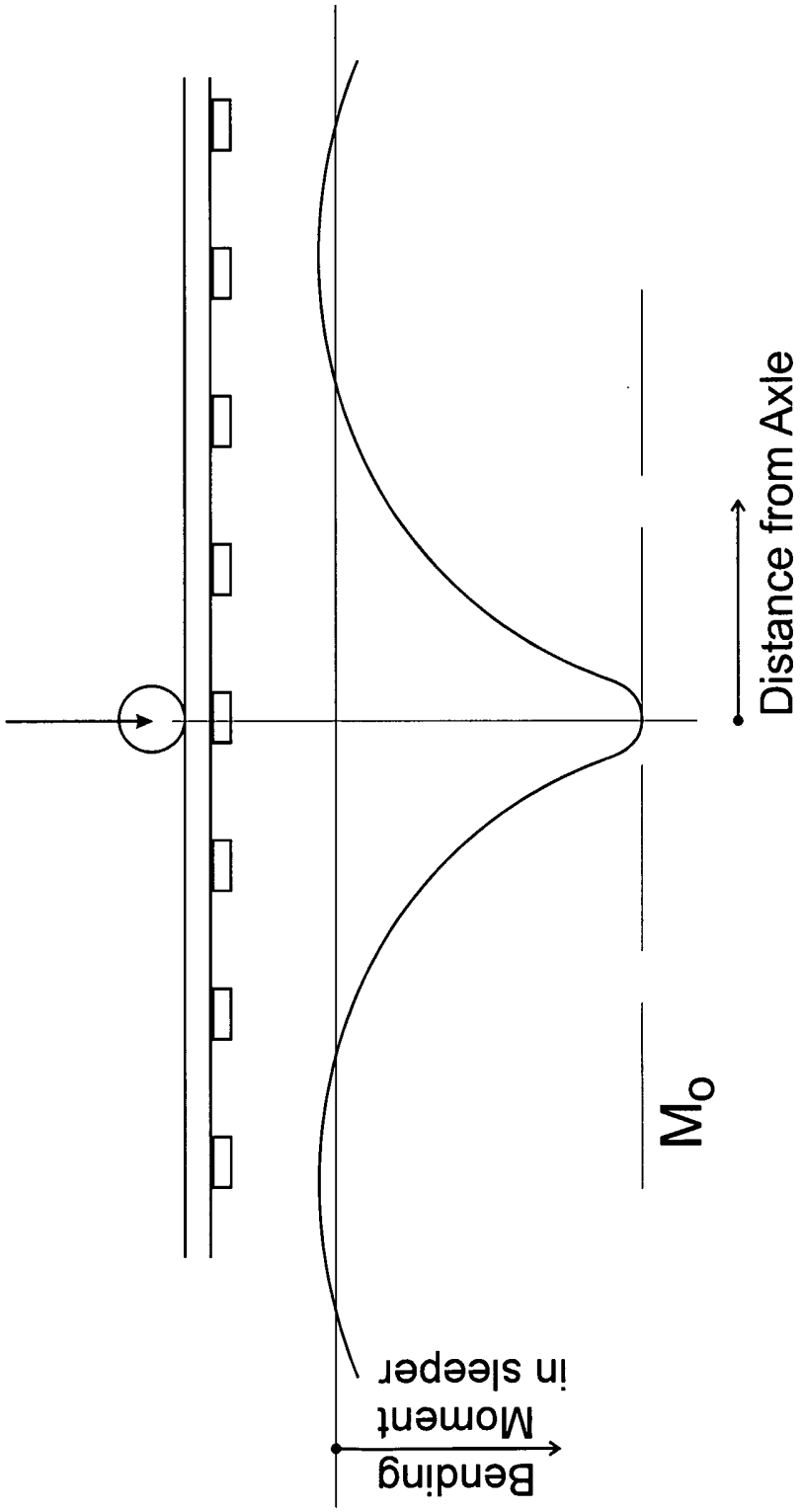


FIG. 4

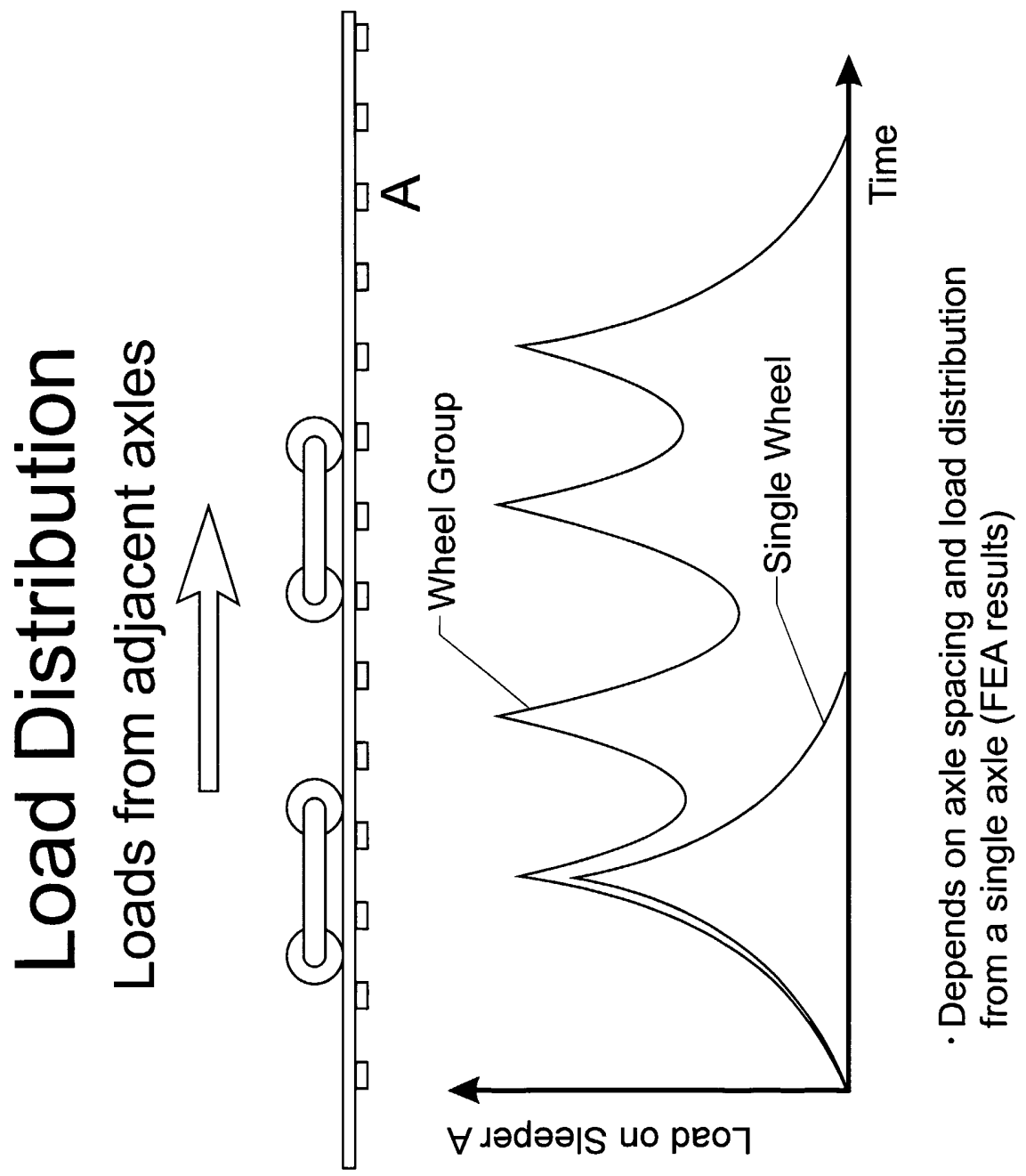
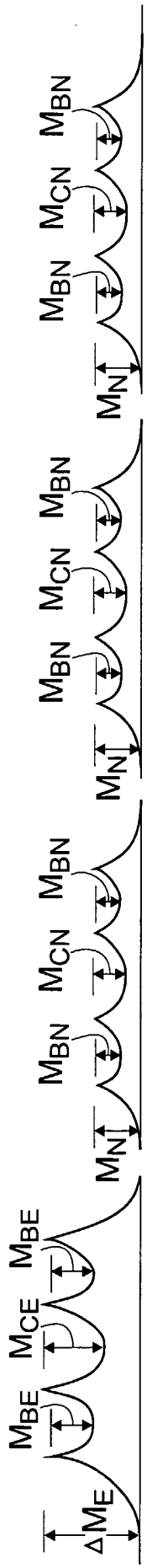

Load Distribution
Loads from adjacent axles
A
Wheel Group
Single Wheel
Time
Load on Sleeper A
• Depends on axle spacing and load distribution from a single axle (FEA results)

FIG. 5

ΔME
ΔMBN
ΔMCN
ΔMBN
Bogie
Coupler
Bogie
ΔME
ΔMBN
ΔMCN
ΔMBN
Bogie
Coupler
Bogie
ΔME
ΔMBN
ΔMCN
ΔMBN
Bogie
Coupler
Bogie
ΔME
ΔMBN
ΔMCN
ΔMBN
Bogie
Coupler
Bogie
Equals
4 Cycles of ΔME
8 Cycles of ΔMBN
4 Cycles of ΔMCN

FIG. 6



Equals

1 Cycle *of* ΔM_E

2 Cycles *of* ΔM_{BE}

1 Cycle *of* ΔM_{CE}

3 Cycles *of* ΔM_N

6 Cycles *of* ΔM_{BN}

3 Cycles *of* ΔM_{CN}

FIG. 7

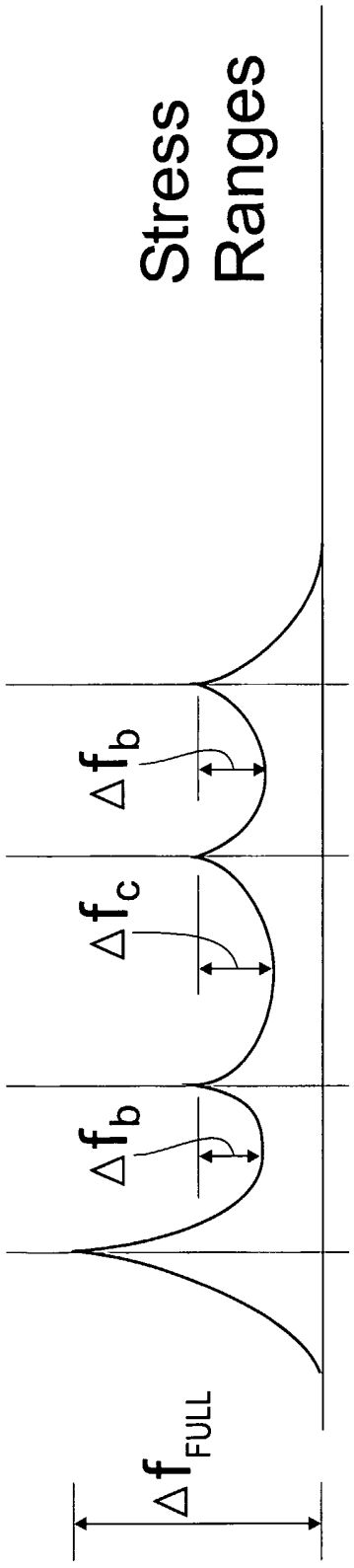


FIG. 8

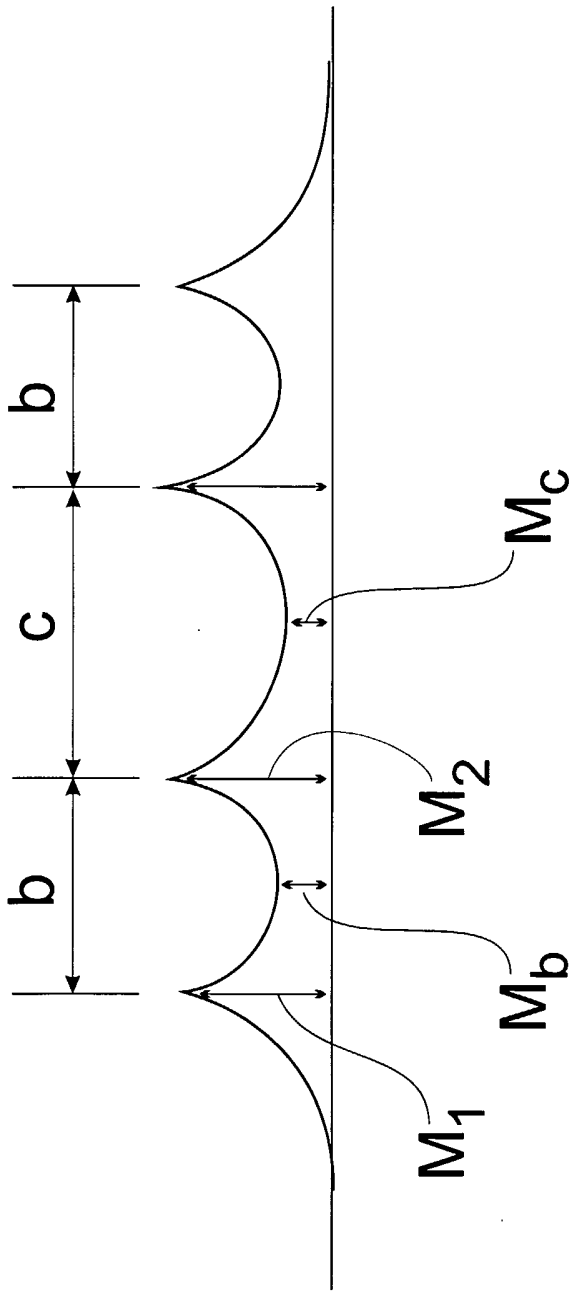


FIG. 9

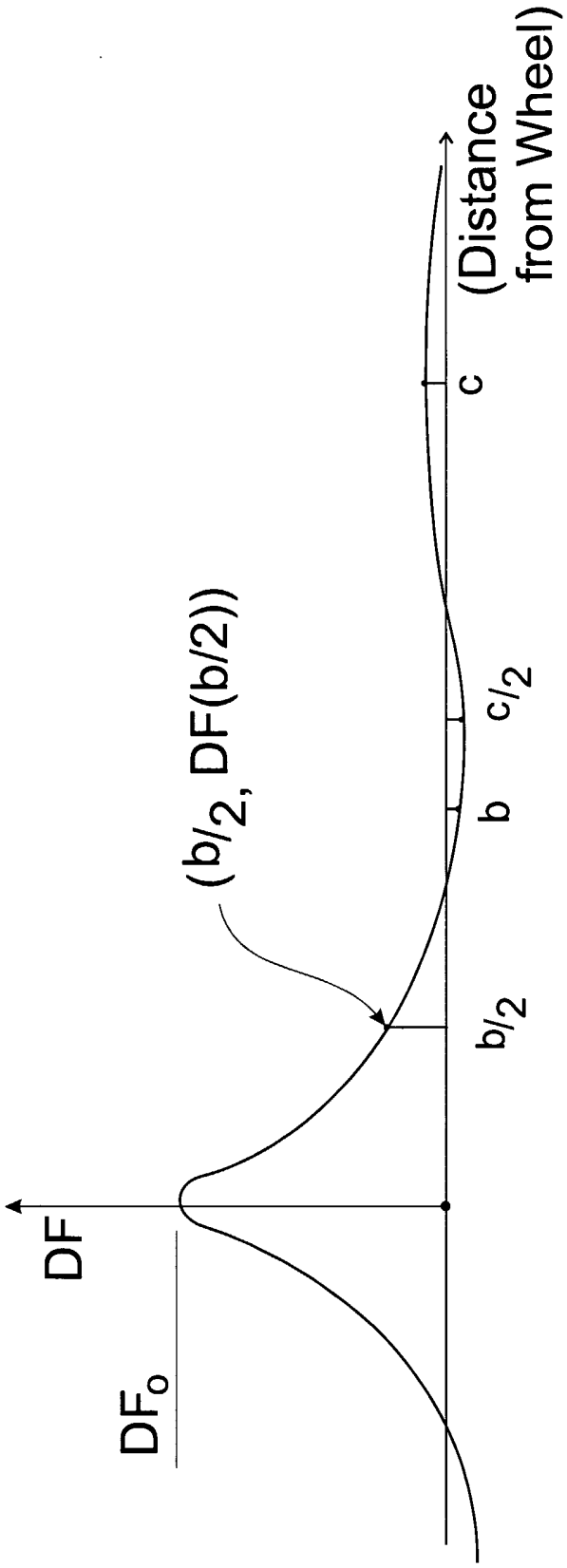


FIG. 10

Fatigue Calculations

Lower 75% of cycles	DIF Min	DIF Max	DIF mean	Number of Cycles	M first axie	σ first axie	fc first axie (top)	fc first axie (btm)	M mid bogie	σ mid bogie
	1	1.0702403	1.03512	8717102	3.42443679	910.00354	13.54357	7.306287	0.83133	903.2615
	1.07024	1.1404807	1.10536	6606328	3.65680941	910.6077	13.82474	7.033249	0.867742	903.4081
	1.140481	1.210721	1.175601	5006660	3.88918202	911.21187	14.10591	6.760211	0.944153	903.5548
	1.210721	1.2809613	1.245841	3794339	4.12155463	911.80996	14.38587	6.486566	1.000565	903.7015
	1.280961	1.3512017	1.316081	2875571	4.35392725	912.40251	14.66471	6.212366	1.056977	903.8481

Lower 75% of cycles	fc mid bogie (top)	fc mid bogie (btm)	M second axie	σ second axie	fc second axie (top)	fc second axie (btm)	M mid coupler	σ mid coupler	fc mid coupler (top)	fc mid coupler (btm)
	10.41175	10.35903	3.427262	910.0108803	13.54899	7.30295755	-0.24007	900.4758	9.121813	11.62329
	10.47973	10.29245	3.659826	910.6155475	13.82839	7.02970449	-0.25636	900.4335	9.102364	11.64251
	10.5477	10.2259	3.89239	911.2202147	14.10979	6.75644144	-0.27265	900.3911	9.082815	11.65173
	10.51568	10.15933	4.124955	911.8186341	14.38995	6.48255361	-0.28894	900.3487	9.063257	11.68095
	10.68365	10.09277	4.357519	912.4116731	14.66902	6.20812774	-0.30524	900.3064	9.043710	11.70010

FIG. 11A

Fatigue Calculations

Lower 75% of cycles	Tendon				Concrete				
	Δσ bogie (MPa)	Δσ coupler (MPa)	#Equiv cycles at Δσ*	Fraction of Fatigue Life	Scdmax Bogie	Scdmin Bogie	Scdmax Coupler	Scdmin Coupler	logN1 bogie
	6.742077	9.535069	0.003332	3.33E-09	0.387151	0.365235	0.387189	0.371772	11.58954
	7.199576	10.18209	0.004559	4.56E-09	0.390315	0.365287	0.390357	0.37202	11.5304
	7.657074	10.82911	0.006015	6.02E-09	0.393594	0.365368	0.39364	0.372275	11.46947
	8.108495	11.46909	0.007647	7.65E-09	0.396941	0.365476	0.39699	0.372535	11.40759
	8.554374	12.10528	0.009412	9.41E-09	0.400352	0.365612	0.400405	0.372802	11.34484

Lower 75% of cycles	Concrete				Modified Provisions
	logN1 coupler	N bogie	N coupler	Fraction of Fatigue Life	Fraction of Fatigue Life
	11.67654	4E+182	5E+259	1.5E-176	1.4639E-176
	11.6195	1.5E+158	1E+216	3E-152	2.8897E-152
	11.56033	4.8E+138	2E+183	7E-133	7.0242E-133
	11.49989	9.3E+122	2E+158	2.7E-117	2.7205E-117
	11.43827	1.1E+110	3.8E+138	1.7E-104	1.6893E-104

FIG. 11B

Fatigue Calculations

Upper 25% of cycles	DIF Min	DIF Max	DIF mean	Number of Cycles	M Peak	σ peak	fc peak (top)	fc peak (btm)	M no load	σ no load
	1.351202	1.591657	1.471429	5516359	5.05127858	914.18076	15.50153	5.389491	0	901.1
	1.581657	1.8321123	1.711885	2135224	5.87613647	916.28415	16.49136	4.416159	0	901.1
	1.832112	2.0725676	1.95234	826483.7	6.70099435	918.42259	17.4847	3.442827	0	901.1
	2.072568	2.3130229	2.192795	319908.1	7.52585223	920.56722	18.47865	2.469494	0	901.1
	2.313023	2.5534782	2.433251	123827.2	8.35071011	922.71185	19.47085	1.496162	0	901.1
	2.553478	2.7939335	2.673706	47929.96	9.17556799	924.85648	20.46419	0.601835	0	901.1
	2.793933	3.0343888	2.914161	18552.31	10.0004259	927.00145	21.47057	0	0	901.1
	3.034389	3.2748441	3.154616	7181.065	10.8252838	929.80596	22.56763	0	0	901.1
	3.274844	3.5152994	3.395072	2779.584	11.8501416	933.26062	23.76871	0	0	901.1
	3.515299	3.7557547	3.635527	1075.897	12.4749995	937.555	25.09275	0	0	901.1
	3.755755	3.99621	3.875982	416.4487	13.2998574	942.87892	26.55273	0	0	901.1
	3.99621	4.2366653	4.116438	161.1953	14.1247153	949.44715	28.15939	0	0	901.1
	4.236665	4.4771206	4.356893	62.39408	14.9495732	957.69573	29.94108	0	0	901.1
	4.477121	4.7175759	4.597348	24.15095	15.7744311	967.80295	31.90089	0	0	901.1
	4.717576	4.9580313	4.837804	9.348139	16.5992889	980.00884	34.02812	0	0	901.1
	4.958031	5.1984866	5.078259	3.618396	17.4241468	994.52845	36.32003	0	0	901.1
	5.198487	5.4389419	5.318714	1.400577	18.2490047	1011.5267	38.74199	0	0	901.1
	5.438942	5.6793972	5.55917	0.542123	19.0738626	1031.1534	41.25522	0	0	901.1
	5.679397	5.9198525	5.799625	0.20984	19.8987205	1054.0844	43.99375	0	0	901.1
	5.919852	6.1603078	6.04008	0.061223	20.7235783	1079.4033	46.68887	0	0	901.1
		Total Cycles Considered =		36000000						

FIG. 11C

Fatigue Calculations

Upper 25% of cycles	fc no load (top)	fc no load (btm)								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								
	9.41	11.34								

FIG. 11D

Fatigue Calculations

	Tendon				Concrete				
Upper 25% of cycles		Δσ (MPa)			Scdmax	Scdmin			LogN1
		13.08076	0.100017	1E-07	0.411079	0.368746			11.18227
		15.18415	0.148143	1.48E-07	0.42454	0.368746			10.92666
		17.32259	0.187704	1.88E-07	0.43873	0.368746			10.65723
		19.46722	0.207723	2.08E-07	0.453437	0.368746			10.37799
		21.61185	0.205953	2.06E-07	0.4685	0.368746			10.09197
		23.75648	0.186797	1.87E-07	0.484539	0.368746			9.787422
		25.90145	0.157413	1.57E-07	0.503384	0.368746			9.429603
		28.70596	0.153696	1.54E-07	0.529105	0.368746			8.941221
		32.16062	0.165434	1.65E-07	0.557265	0.368746			8.406531
		36.455	0.197838	1.98E-07	0.588307	0.368746			7.817105
		41.77892	0.261157	2.81E-07	0.622537	0.368746			7.167163
		48.34715	0.376197	3.76E-07	0.660205	0.368746			6.451923
		56.59573	0.601065	6.01E-07	0.701978	0.368746			5.658761
		66.70295	1.020856	1.02E-06	0.747926	0.368746			4.786306
		78.90884	1.793002	1.79E-06	0.7978	0.368746			3.839323
		93.42845	3.173608	3.17E-06	0.851534	0.368746			2.819027
		110.4267	3.003557	3E-06	0.908318	0.368746			1.740833
		130.0534	2.634295	2.63E-06	0.967241	0.368746			0.622011
		152.9844	2.296589	2.3E-06	1.031447	0.368746			-0.59711
		178.3033	1.911766	1.91E-06	1.094635	0.368746			-1.7969
Total number of equivalent cycles at Δσ*			18.81378	1.88E-05					

FIG. 11E

WO 2004/018772 PCT/AU2003/001074

Fatigue Calculations

	Concrete				Modified Provisions
Upper 25% of cycles		N	Nmod	Fraction of Fatigue Life	Fraction of Fatigue Life
		9.86E+86	9.86E+86	5.6E-81	5.60E-81
		7.53E+62	7.53E+62	2.83E-57	2.83E-57
		3.67E+47	3.67E+47	2.25E-42	2.25E-42
		1.48E+37	1.48E+37	2.17E-32	2.17E-32
		5.63E+29	5.63E+29	2.2E-25	2.20E-25
		1.06E+24	1.06E+24	4.54E-20	4.54E-20
		1.25E+19	1.25E+19	1.49E-15	1.49E-15
		2.1E+14	2.1E+14	3.43E-11	3.43E-11
		2.84E+12	2.84E+12	9.8E-10	9.80E-10
		4.55E+10	4.55E+10	2.36E-08	2.36E-08
		6.92E+08	6.92E+08	6.02E-07	6.02E-07
		10841180	10841180	1.49E-05	1.49E-05
		455786.4	455786.4	0.000137	1.37E-04
		61137.3	61137.3	0.000395	3.95E-04
		5907.54	6907.54	0.001353	1.35E-03
		659.2154	832.0133	0.005489	4.35E-03
		55.05958	278.1534	0.025437	5.04E-03
		4.188046	89.22945	0.129445	6.08E-03
		0.252868	25.85041	0.829842	8.12E-03
		0.015963	7.837594	5.088357	1.06E-02
	Total Fraction of Fatigue Life (concrete)			6.080472	3.61E-02

FIG. 11F

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU03/01074

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: E01B 3/28, 3/30, 3/32, 3/36, 3/38, 3/40

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI:: IPCClass Marks E01B 3/28, 3/30, 3/32, 3/36, 3/38, 3/40 + Keywords (Design, Fatigue, Stress, Load)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Derwent Abstract Accession No.95-177069/23, Class Q41, RU 2020455C1 (KLINOV), 30 September 1994	1-20
A	Derwent Abstract Accession No.92-122582/15, Class S02 S03, SU 1651135A (KHARK RAIL TRANSPORT), 23 May 1991	1-20

☐ Further documents are listed in the continuation of Box C ☐ See patent family annex

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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Date of the actual completion of the international search	Date of mailing of the international search report
23 October 2003	30 OCT 2003
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer **G.B. NATH** Telephone No : (02) 6283 2126