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NDT and Railway Trackbed Stiffness

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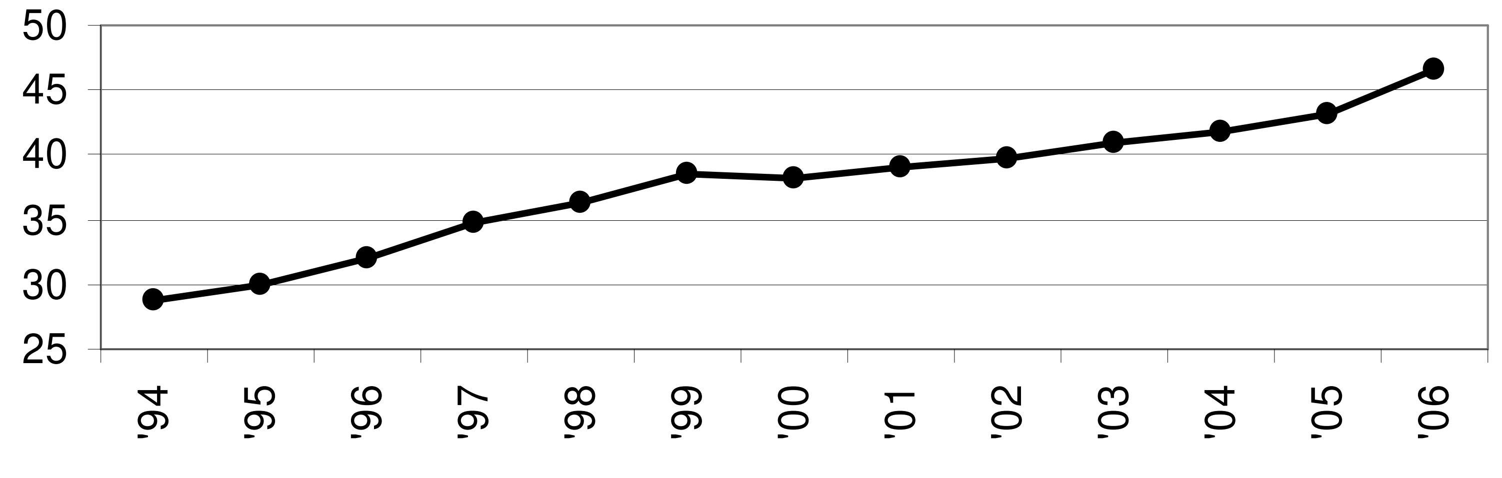
Background and Motivation

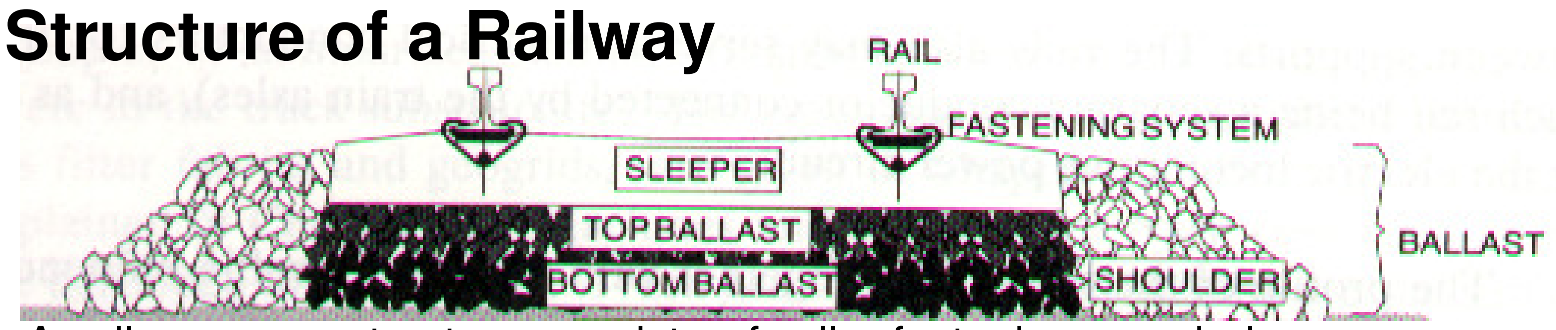


UK Billion Rail Passenger Miles Travelled Per Year

•Distances travelled by UK rail passengers have increased over 1994-2006.

•Consequently, desire to find new methods to reduce maintenance costs.

Structure of a Railway



•A railway superstructure consists of rails, fastenings, and sleepers; over a substructure of a crushed granular ballast layer on a formation layer.

•Ballast resists imposed rail forces, maintains alignment, provides drainage.

•Ballast becomes "spent" over time through weathering, mechanical interaction and fouling where fine particles accumulate in the void structure.

•"Spent" ballast fails to provide drainage and mechanical functions required.

•Industry requires method of ballast evaluation that is non-intrusive, cheap, can quickly appraise long stretches, and gives "time-to-maintenance".

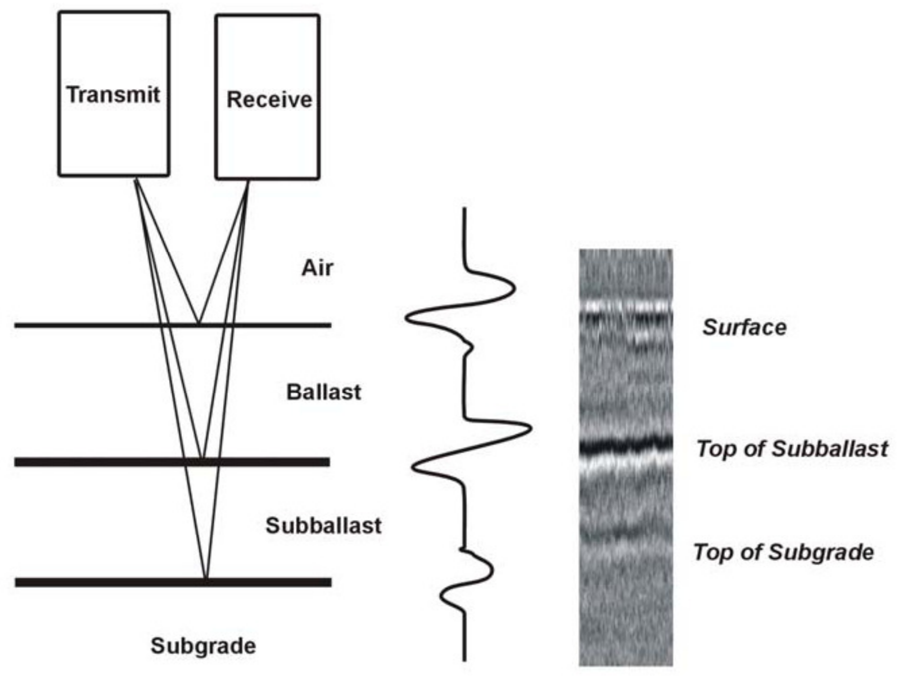
Ground Penetrating Radar (GPR)

•A transmitting antenna radiates microwave pulses into the ground and a receiving antenna measures variations in the reflected signal time profile.

•For pulsed GPR systems, the transmitted pulse is a single bipolar pulse. Reflections occur as the signal moves through material interfaces.

•These interface reflections give the responses from which the underground structural profile can be inferred.

•The diagram of a railway profile (left of diagram) is matched against a typical "wiggle plot" response profile (middle), and the combination of several "wiggle plots" to produce an underground radar image profile (right).



$$v = \frac{c}{\sqrt{\varepsilon_r}}$$

•Velocity of signal propagation is related to the speed of light and a material property: the dielectric constant of the medium.

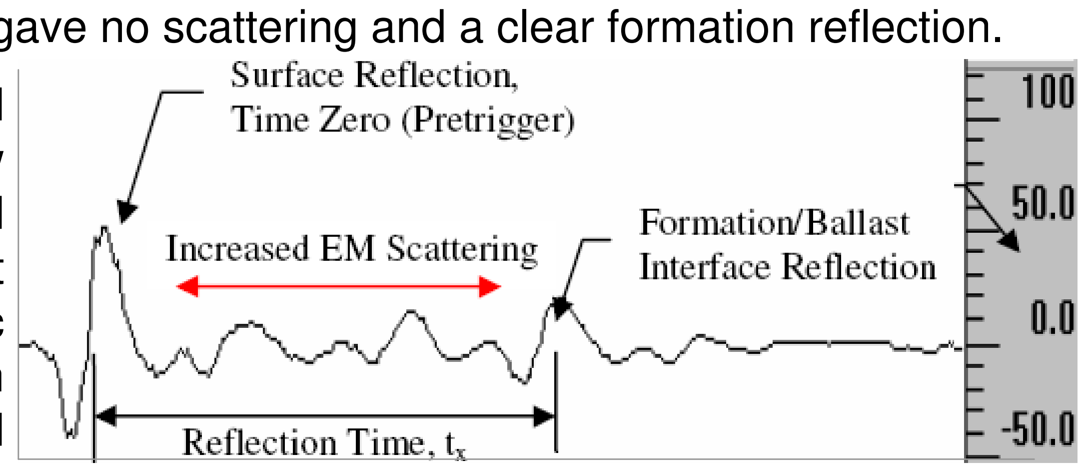
•Water has a constant of 1, water of 80, and dry ballast 3-8.

Previous University of Edinburgh Research

•Signal propagation varies with condition of the ballast: $1.73*10^8$m/s dry clean, $1.60*10^8$m/s wet clean (5% moisture), and $1.45*10^8$m/s dry spent.

•Signals through spent ballast produced scattering and unclear formation reflection; clean ballast gave no scattering and a clear formation reflection.

•Results were attributed to loss of voids (with low dielectric value), and replacement with moist fines (with high dielectric value), resulting in increased scattering and attenuation.



Current Research

•Experimentation on the University of Edinburgh track showed that a relationship between condition of ballast and dielectric values existed.

Ballast	Sleeper Space	Formation depth (m)	Formation at sample (512=50ns)	Rebase sample (less 70)	Reflection time (ns)	Velocity (m/s)	εv	Ave εv
Clean	1-2	0.311	121	51	5.0	124,887,843	5.8	
	2-3	0.340	124	54	5.3	128,948,148	5.4	
	3-4	0.372	125	55	5.4	138,519,273	4.7	5.25
	4-5	0.360	125	55	5.4	134,050,909	5.0	
	5-6	0.350	125	55	5.4	130,327,273	5.3	
	6-7	0.355	126	56	5.5	129,828,571	5.3	
Mixed	7-8	0.320	124	54	5.3	121,362,963	6.1	
	8-9	0.346	126	56	5.5	126,537,143	5.6	
	9-10	0.360	125	55	5.4	134,050,909	5.0	5.73
	10-11	0.340	124	54	5.3	128,948,148	5.4	
	11-12	0.345	130	60	5.9	117,760,000	6.5	
Spent	12-13	0.335	125	55	5.4	124,741,818	5.8	
	13-14	0.325	125	55	5.4	121,018,182	6.1	
	14-15	0.331	126	56	5.5	121,051,429	6.1	5.99
	15-16	0.310	123	53	5.2	119,788,679	6.3	
	16-17	0.315	121	51	5.0	126,494,118	5.6	

•300km of rail track stiffness and radar data was provided by Swedish Rail.

•Stiffness data was collected continuously from measured wheel axle acceleration from two oscillating masses that dynamically excited the track.

•The stiffness data was recorded at 0.5m metre intervals.

•300kHz horn antenna took 10 scans per metre at 512 samples per scan.

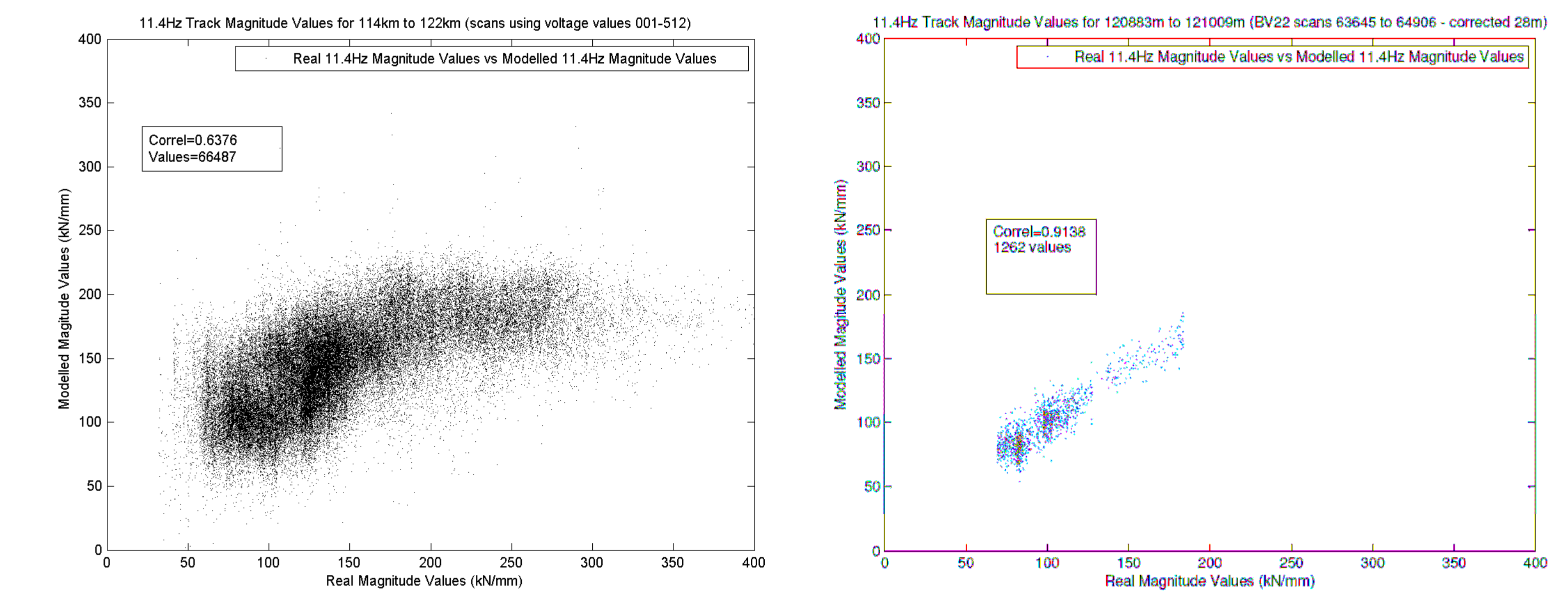
•Multivariate regression used to compare radar data with stiffness data.

•A numerical model was created: vector [Y] of stiffness values at locations 1 to m equated to matrix [X] of reflectivities at depths 1 to n (512 samples) at locations 1 to m multiplied by a vector [b], which, when solved, relates GPR reflectivities at each location to track stiffness.

$$\begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_m \end{bmatrix} = \begin{bmatrix} 1 & X_{11} & \cdots & X_{1n} \\ 1 & X_{21} & \cdots & X_{2n} \\ \vdots & \vdots & & \vdots \\ 1 & X_{m1} & \cdots & X_{mn} \end{bmatrix} \begin{bmatrix} b_0 \\ b_1 \\ \vdots \\ b_n \end{bmatrix}$$

•The [b]-vector was used to re-calculate the track stiffness values from those same GPR values, the relationship between the measured ("Real") stiffness and computed ("Modelled") stiffness values was plotted.

•There was some degree of correlation between the stiffness data and the "Real" values and the "Modelled" values indicating that where some stiffness data can be analysed against radar data, this relationship can be extrapolated and stiffness values determined from other radar data. The relationship improved where a smaller, and apparently more homogenous area of track was used: -



Future Research

1. Visit Banverket track to assess physical characteristics tracks involved.
2. Investigate credibility of the postulated relationship between GPR electromagnetic measurements and trackbed stiffness.
3. Investigate the correlation between GPR and previous mini falling weight deflectometer results.
4. Investigate the viability of identifying percentage fines in ballast.
5. Investigate the viability of other geophysics techniques, such as "continuous surface measurements".

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