DESIGN, MANUFACTURE, SUPPLY, TESTING, COMMISSIONING AND TRAINING OF 378 NOS. OF STANDARD GAUGE METRO RAIL CARS FOR MUMBAI METRO RAIL INVESTMENT PROJECT

CONTRACT AGREEMENT
CONTRACT 'MRS1'

PART-I

PROCEDURE FOR SAFETY CERTIFICATION AND TECHNICAL CLEARANCE OF METRO SYSTEMS

सत्यमेव जयते

GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS

Procedure for Safety Certification and Technical Clearance of Metro Systems

December 2015

Urban Transport & High Speed Directorate

RESEARCH DESIGNS & STANDARDS ORGANISATION

MANAK NAGAR, LUCKNOW – 226 011

Changes in present version (December 2015) of Procedure for Safety Certification and Technical Clearance of Metro Systems with respect to previous version of February 2015

S.N.	Modification in	Edited/Removed/ Added	Authority
1	Ann C-1 Clause 3.2	Item (viii) added for gradients	Rly Bd letter no.2010/Proj./ Bangalore/30/4-Vol.II (Pt.) dtd 23.09.2015
2	Ann C-1 Clause 8.1	Para modified to cater for provisions for single track tunnel	Rly Bd letter no. 2011/Proj./ MOU/31/1 Vol. I dtd 26.11.2015
3	Ann C-1 Clause 14	Para added for gradients	Rly Bd letter no.2010/Proj./ Bangalore/30/4-Vol.II (Pt.) dtd 23.09.2015
4	Ann C-2 Clause 4.1(ii)	Para modified	Rly Bd letter no. 2011/Proj./ MOU/31/1 Vol. I dtd 18.11.2015
5	Ann C-2 Clause 4.7 Table 1	Table modified	Rly Bd letter no. 2011/Proj./ MOU/31/1 Vol. I dtd 18.11.2015

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ANNEXURES

PROCEDURE FOR SAFETY CERTIFICATION AND TECHNICAL CLEARANCE OF METRO SYSTEMS BY RDSO

1. GENERAL

As per Amendment to Metro Railway (Operation and Maintenance) Act 2009, Indian Railways have been unambiguously given the responsibility of technical planning and safety of Metro Systems being implemented in India. Since a number of Metros are coming up in various cities of India, considering the fact that some technical and safety related issues can best be dealt with at the planning stage itself, a comprehensive document has been prepared giving the details of procedure for Safety Certification and Technical clearance of Metro Systems by RDSO, Ministry of Railways.

2. SCOPE

This is a reference document defining the procedure and the various steps to be taken for safety certification and technical clearance of Metro Systems being implemented in India. This will provide guidance to the authorities who intend to plan, construct and operate a Metro System in India. After deliberations in the Inter-Ministerial Committee on Metro issues, it was decided with general consensus, that Ministry of Railways should confine its role to according in principle approvals of broad technology as chosen and proposed by the metro railway administrations in the following areas:

i. Schedule of Dimensions
ii. Design Basis Report
iii. Track structure
iv. Oscillation trials of rolling stock as required
v. Issue of Speed Certificate
vi. Technology for signalling
vii. Technology for traction
viii. Rules for opening of the metro railway and General Rules

3. OVERVIEW OF THE PROCEDURE

3.1. The complete exercise of Safety Certification and Technical Clearance for commissioning a Metro System for passenger service is broadly divided into the following parts:

1. Submission and Scrutiny of Schedule of Dimensions (SOD)
2. Submission and Scrutiny of technical documents like specifications, design and test certificates.
3. Tests of selected sub-systems.
4. Oscillation trials and issue of speed certificates.

3.2. However, before the actual start of process for Safety Certification and Technical Clearance, it is advisable that Metro administration keeps RDSO generally informed about the project developments and starts liaison well in advance. To make this a part of the system, a copy of the Detailed Project Report (DPR) approved by Ministry of Railways and Ministry of Urban Development may be sent to RDSO.

3.3. The Metro administration shall submit the required documents to Executive Director Works (Planning) Railway Board, and also send a copy of the same to Executive Director, Urban Transport and High Speed Directorate, RDSO, Manak Nagar, Lucknow. UTHS directorate will co-ordinate within RDSO and with the Metros for scrutiny of documents and certification of Metro. These steps have been explained in detail in the following paragraphs:

4. SUBMISSION AND SCRUTINY OF SCHEDULE OF DIMENSIONS (SOD)

[Expected Time for examination and clearance of SOD - Three months]

Initially Metro Administration is required to submit its **SOD** for approval. It should comprise of general alignment and clearances, rolling stock dimensions, kinematic envelope and structure gauge, clearances at stations and platforms, type of electric traction and clearances from live parts. If a Metro is being extended, then fresh SOD will not be required to be approved.

5. SUBMISSION AND SCRUTINY OF DOCUMENTS.

[Expected Time for scrutiny of documents –six weeks]

Metro Administration is required to submit documents, duly approved by Metro Administration as per annexures mentioned below. Sub-system wise break up of these documents is as follows:

5.1. **Rolling Stock(Mechanical Part):**as per **Annexure A**

5.2. **Rolling Stock (Electrical Part)**: as per **Annexure B**

5.3. **Track**: The following documents are required

a) Compliance of Standards for Track Structure and salient feature of Track Structure adopted by Metro Railways **(Annexure C1)**

b) Compliance to Performance criteria of Fastening System for ballastless track on Metro Railways/MRTS and salient feature of Fastening System adopted by Metro Railway **(Annexure C2)**

5.4. **Traction Installation and Power Supply :** as per Annexure D1 and D2

5.5. **Bridges and Structures**

a. A copy of Design Basis Report (DBR) for viaduct and other bridges duly approved by the metro authorities is required to be submitted prior to taking up design work by the Consultant. This shall require approval of Ministry of Railways before start of physical work.

b. It should include load model, provisions of various Codes and Manuals to be followed with preference (Justification should also be furnished if other than IRS Code are proposed to be followed), type of construction material etc.

Notes:

i. A Model DBR has been prepared by RDSO/ MoR and same has been uploaded on RDSO website. Metros should refer it for preparing their DBR.

ii. RDSO has prepared guidelines for carrying out RSI studies and same has been uploaded on RDSO website. This may be referred for doing RSI studies.

5.6. **Signalling**

a. Documents are required for various sub-systems duly approved by Metro authorities as per **Annexure E1.**

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b. A Broad description of the systems in line with already approved system of Metro Signalling System and & telecommunications system is available at **Annexure E2**. For Technical clearance, minimum provisions to be adopted for Signalling systems & telecommunications systems are outlined in this annexure. Deviations, if any, shall be pointed out clearly.

6. SUBMISSION OF TEST CERTIFICATES / Reports

6.1 The following test certificates are required to be submitted to RDSO for record before conducting oscillation trial:

6.1.1. **Rolling Stock –Mechanical**

i. Type test of coupler
ii. Type test of brake system
iii. Type test of wheels and axles
iv. Prototype test of Bogie frame
v. Endurance test of Bearing
vi. Compliance certificate for crashworthiness standard

[Expected Time in scrutiny and examination of these certificates – four weeks]

6.1.2. **Rolling Stock– Electrical**

Dynamometer car test certificate giving starting and rolling resistance of the Prototype Rolling Stock and verifying the "tractive effort-speed" and "regenerative braking effort/speed" characteristics; along with methodology of acquisition of data and calculation method. If Dynamometer car test is not being conducted for the rolling stock, then test results by manufacturer for similar test done earlier to be provided.

[Expected Time in scrutiny and examination of these certificates – four weeks]

6.2. The following test certificates are required to be submitted to RDSO for record **before commissioning of the corridor**.

6.2.1. **Signal and Telecommunication:** Completion report of Integrated **Testing and Commissioning Tests** with their results for Signalling/Train Control Systems and Tele Communication Systems.

6.2.2. **Rolling Stock– Electrical:** EMC/EMI compatibility test report to be submitted before commissioning of the corridor.

7. OSCILLATION TRIALS AND ISSUE OF SPEED CERTIFICATEs

7.1. The following types of speed certificates are issued by RDSO.

i. Speed certificate for **conducting oscillation trials** of the rolling stock by RDSO to ascertain its maximum speed potential. (Test methodology and criteria for the test are enclosed as **Annexure F1& F2** respectively).

[Expected Time in issuing this certificate – two weeks]

ii. Speed certificate for **conducting Emergency Braking Distance trial** for the complete train formation intended to be operated. (Test methodology is enclosed as **Annexure G1** and parameters required are at **Annexure G2**).

[Expected Time in issuing this certificate – two weeks]

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iii. Speed certificate for **conducting COUPLER FORCE, CONTROLLABILITY** or any other special trial. Coupler force trials shall be necessary for sections having sustained up gradient steeper than 1 in 100. Controllability trials shall be necessary for sections having sustained gradient steeper than 1 in 100. (Test methodology for coupler and controllability are enclosed as **Annexure H** and **Annexure I** respectively).

NOTE: These trials may be dispensed with by RDSO, if Metro Authorities submit adequate details of design calculations and Type test reports of couplers and brake system certifying their suitability for use in the worst operating conditions, which shall also include failure of ATP/CBTC.

[Expected Time in issuing this certificate – two weeks]

iv. **Provisional speed certificate** for operation and regular use of new design of rolling stock without conduct of detailed oscillation trials. The provisional maximum permissible speed for new design of rolling stock will be determined on the basis of design features and data, and where appropriate also on a comparison of the performance of similar design of stock already in service, generally in line with Policy Circular no. 6 issued by Railway Board.

v. **Interim speed certificate** for operation and regular use of rolling stock at the maximum permissible speed as determined in oscillation trials and based on norms set by Criteria Committee of RDSO (**Annexure F2**) and in EBD trials.

vi. **Final speed certificate** for operation and regular use of rolling stock at the maximum permissible speed based on norms set by Criteria Committee of RDSO (**Annexure F2**), after conduct of oscillation trials over rundown track with worn wheel profile, as soon as available, and with instrumented measuring wheel wherever required.

[Expected Time in issuing this certificate – two weeks]

7.2. Prior sanction of CRS for conducting trials

a) In cases where metro line is yet to be opened for public carriage of passengers, prior sanction of CRS will not be needed for conducting Oscillation, EBD, coupler forces and other such trials of coaches, mentioned in para 7.1 (I, ii and iii). After issue of speed certificate by RDSO for such trial, the concerned Metro will submit the documents already prescribed to RDSO.

b) However, prior sanction of CRS will continue to be mandatory for conducting all the trials mentioned in para 7.1 (i,ii and iii), where the Metro line has already been opened for public carriage of passengers and a new design of Rolling Stock is to be tested or where speed of an existing rolling stock is to be increased. Requisite papers and certificates will need to be submitted by concerned Metros to CRS for this purpose.

7.3. For oscillation trial and speed certificate of metro rolling stock as described above, the concerned metro corporation shall apply to Executive Director (Urban Transport & High Speed), Research Designs and Standards Organization, Manak Nagar, Lucknow-226011.

7.4. Application for getting **oscillation trial** done shall be accompanied by the following documents:

i. Performance report of the existing operation.
ii. Full details of the rake composition & section on which trial is proposed.
iii. Joint Safety certificate issued by concerned Metro
iv. Track certificate issued by concerned Metro
v. Bridge Certificate issued by concerned Metro
vi. After issue of Speed Certificate, CRS sanction for conducting the trial, if necessary in terms of Para 7.2
vii. An Indemnity Bond by the concerned Metro administration indemnifying RDSO / Indian Railways for damages if any, caused by any accidents/casualties during such trials.
viii. Any other certificate required as per CRS sanction, if necessary in terms of Para 7.2

7.5. Application for getting **special trials** done shall be accompanied by:

a. Joint Safety certificate issued by concerned Metro
b. Track certificate issued by concerned Metro
c. Bridge Certificate issued by concerned Metro
d. After issue of Speed Certificate, CRS sanction for conducting the trial, if necessary in terms of Para 7.2
e. An Indemnity Bond by the concerned Metro administration indemnifying RDSO / Indian Railways for damages if any, caused by any accidents/casualties during such trials.
f. Any other certificate required as per CRS sanction, if necessary in terms of Para 7.2

Apart from above, details indicated in annexures G1 and G2 for **Emergency /Service Braking Distance trials**, in annexure H for **Coupler Force trial** and in annexure I for **Controllability trial**, following documents will also be required:

7.6. In addition to the above mentioned documents, any other detail required by RDSO after due examination of the case, shall be intimated to the concerned metro.

[Expected Time in conducting oscillation trial by RDSO – four weeks. Additional 2 weeks for EBD trial and 2 weeks for coupler force trial if needed.]

7.7. For issuing of Provisional / Interim Speed Certificate, following shall be required:

i. Approved Schedule of dimensions (SOD) and condonation letter from Railway Board for infringements/deviations, if any, from approved Schedule of dimensions (SOD).
ii. Approval of Track Structure and Fastening System as per Annexure C1 & C2 and condonation letter from Railway Board for deviations, if any, from approved Track Structure and Fastening System
iii. Approved Design Basis Report.
iv. In principal approval of Traction System as per Annexure –D1/D2
v. Complete design details pertaining to vehicle dynamics along with drawings of the rolling stock – As per Annexure A & B
vi. Report of Vehicle dynamics simulation done including Vertical acceleration values, Lateral acceleration values, Vertical Ride Quality, Lateral Ride Quality, Vertical

force, Max. Lateral force, Derailment Coefficient (Lateral force/ Instantaneous wheel load.)

7.8. After receiving speed certificate for passenger carrying rolling stock, Metro administration shall apply for sanction for the same to the Railway Board /MoR through Commissioner of Railway Safety of the Circle in whose jurisdiction the Metro falls, as per the provision stipulated in "Opening of Metro Railway for Public Carriage of Passenger Rules, 2013" with latest amendment.

7.9. For existing rolling stocks, where there is a case of design modification or speed enhancement, as defined in "Opening of Metro Railway for Public Carriage of Passenger Rules, 2013", with latest amendment, the same procedure, as described above, shall be followed.

8. CONDONATION:

8.1 Any deviation from the standards prescribed by and acceptable to MOR, either pointed out by MOR/RDSO or brought to the notice of MOR/RDSO by the Metro, will be required to be condoned by MOR. For any such condonation Metro will submit detailed justification each case wise well in advance.

8.2 Any infringement or deviation to approved SOD will also require condonation from MOR. However, the case is to be processed as under:

i) By Metro through approval of concerned CRS to Railway Board in case of fixed installations.

ii) By Metro through RDSO and CCRS in case of infringements to SOD by Rolling Stock.

9. MAINTANCE AND OTHER MANUALS

Before commencement of the commercial services, the Metro Administrations should ensure that all the following manual are in place:

a) Operations Manual
b) Safety Manual
c) Disaster Management Manual
d) Maintenance Manual of various sub-systems

10. The expected time stipulated is tentative and does not include the time taken by Metros in providing any clarification asked by RDSO.

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Annexure-A

Documents required for issue of speed certificate of Rolling Stock - (Rolling Stock - Mechanical)

1. **Brake System**
   i. System description of air supply and brake system, Standards followed.
   ii. Train brake calculation and parking brake details.
   iii. Emergency braking distance.
   iv. Air consumption calculation.
   v. Brake and piping diagram.

2. **Bogie System**
   i. System description of bogie.
   ii. Drawings and Design Data for Bogie
   iii. Finite Element Analysis Report of Bogie Frame.
   iv. Fatigue test data of bogie frame and endurance parameters calculations
   v. Thermal calculation of wheel.
   vi. Axle strength calculation-Powered axles.
   vii. Axle strength calculation- Non - Powered axles.
   viii. Life rating calculation of axle box bearing.
   ix. Suspension drawing and design parameters.

3. **Vehicle Dynamic Analysis on Track Data as Specified by Metro Administrations**
   i. Vehicle model.
   ii. Natural frequencies of the suspension.
   iii. Stability / safety of bogie
   iv. Wheel / track off-loading.
   v. Bogie rotational resistance.
   vi. Wheel wear index at the tread and flange.
   vii. Lateral force and derailment quotient.
   viii. Ride index.
   ix. Acceleration values of car body and bogie frame.
   x. Criteria for assessment of riding behaviour of vehicle.

4. **Finite element Analysis of car body structure as per manufacturer**
5. **Relative movement between coaches/coach and bogie**
   i. Coupler movement calculation
   ii. Gangway movement calculation for specified radius
   iii. Calculation of relative movements between coach and bogie on different degrees of curvature.
6. **Passenger Saloon Door description & Drawing for record purpose**
7. **Coupler – Technical description and drawings.**

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8. **Fire load calculation and emergency evacuation of passengers**
   i. Design calculation of Fire load above and below body frame.
   ii. Fire Protection System and compliance to relevant International Standards.
   iii. Measures for emergency evacuation of passengers.

9. **Crashworthy Simulation as per EN 15227 and GMRT 2100**

10. **Layout of DMC and TC and pay load calculation.**

11. **Weight particulars of stock.**

12. **Test Procedure of Brake System, Bogie, Coupler, Wheel & Axle to be given for information.**

i. **Brake System**
   a. Dynamometer test.
   b. Brake calliper unit.

ii. **Bogie System**
   a. Static and Fatigue tests of bogie frame
   b. Bogie rotational resistance test
   c. Oscillation trials
   d. Wheel offloading test

iii. **Coupler System**
   a. Test specification of coupler

iv. **Wheel & Axle**
   a. Test procedure of Wheel.
   b. Test procedure of Wheel set.
   c. Test procedure of Solid Axle.

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Annexure-B

Documents required for Rolling Stock - (Rolling Stock - Electrical)

1. Technical specification on rolling stock covering its electrical sub systems for information:

2. Following Design Calculations to be furnished for records sake:-
   (i) Adhesion calculation
   (ii) Gear pinions, analysis of stresses, selection of bearing, gear case and transmission assembly
   (iii) Tractive and braking effort vs speed curves showing balancing speed.
   (iv) Curves of efficiency, power factor, frequency, slip as a function of speed.
   (v) Traction Motor performance curves.
   (vi) Harmonic calculations.

3. Following drawings to be furnished for information :-
   (i) Schematic diagram of power, dynamic braking, control and auxiliary circuits including multiple operations.
   (ii) Tractive effort transmission diagram.
   (iii) Brake system schematic diagram.
   (iv) Drawing showing mounting arrangement of traction motor.
   (v) Motor suspension arrangement.
   (vi) Power converter cooling arrangement.
   (vii) General arrangement for wheel slip detection and correction system.
   (viii) Drawings for third rail current collector.
   (ix) Air Conditioning arrangement.

4. EMI/EMC compatibility, test plan & results.
5. Simulation results for TE, BE, Performance curves for rolling stock for identified section of Metro.
6. Details of electrical protection system of metro unit, various equipment and their sub-assemblies.
7. Safety plan and standards followed and references for provenness of major assemblies and sub-assemblies.

Part-A: Technical Standards of Track Structure for Metro Railways/MRTS (Compliance to be given)

1. Scope:

To stipulate the desirable technical standards /specifications for track structure for Metro Railways/ MRTS Systems in the country.

2. Operating Environment:

Track Structure should fulfil generally the following conditions:

2.1 Gauge – Broad gauge- 1676/1673mm (nominal) and standard gauge – 1435mm.
2.2 Rail Seat inclination (slope): 1 in 20
2.3 Speed potential – 110 kmph (max.)
2.4 Static axle load –20 T (max.)
2.5 Design rail temperature range – (-)10 degree Celsius to (+) 70 degree Celsius
2.6 Maximum Curvature and ruling gradient - As specified in SOD

3. Track Structure:

3.1 General: The track structure should fulfil the following requirements:

3.1.1 The track structure should conform to/ satisfy Schedule of Dimension requirement and other maintenance instructions of Metro systems.

3.1.2 Ride comfort and running safety of track vehicle dynamics should be satisfied.

3.1.3 The track structure should be designed with Long welded / Continuously welded rail on main line track in case of ballasted as well as ballastless track.

3.1.4 The horizontal alignment shall consist of a series of straights joined to circular curves generally with transition curves. Curvature and cant shall be calculated based on the train speed for each train type on the section. Compound and reverse curves are acceptable, provided they are connected by an adequate transition curve.

3.1.5 The vertical alignment should be designed to achieve a smooth profile line with gradual changes. Changes in the profile should be connected by vertical curves, which shall be as generous in length as the location allows. Vertical curves including its transition shall not be located at stations within the length of platform. A vertical curve within the length of transition and Turnouts is also not desirable. Vertical curve radius is constrained by the need to limit the vertical acceleration for passenger ride comfort.

3.2 The technical standards for Track structure deals with the following components-

(i) Rail and Welding
(ii) Sleeper and fastening for ballasted track
(iii) Track slab for ballastless track
(iv) Fastening system for ballastless track
(v) Insulated Glued joint
(vi) Turnout, scissors crossover
(vii) Switch Expansion Joints
(viii) Gradients

4. Rails and Rail Welding:

4.1 Rails:

4.1.1 For Main line Track:

4.1.1.1 The rail used on main line on curves and approaches of Stations shall be 60E1 (UIC 60), 1080 grade Head Hardened.

4.1.1.2 At other locations on straight line of main line, the use of 60E1 (UIC 60), 1080 grade HH / 60E1 (UIC 60), 880 grade rail shall be decided by Metro Railway depending upon speed, axle load and other factors pertaining to safety and life of rail. However on curves with small straight track in between, the 60E1 (UIC 60), 1080 grade Head hardened rail should be continued on straight patches also.

4.1.1.3 It is essential to have preventive rail grinding arrangements in case 60E1 (UIC 60), 1080 HH rails are used.

4.1.2 For Depot lines:

The rail used on depot lines can be non- head hardened and shall be 60E1 (UIC 60), 880 grade.

4.1.3 Specification:

4.1.3.1 The rail shall be class 'A' rails as per IRS-T-12-2009 specification with latest amendments. However, any suitable length of rail more than 13 m considered appropriate by metro on consideration of transportation and handling can be adopted, provided the rails are ultimately welded into long welded rails.

4.1.3.2 The rail shall be manufactured and tested in accordance with IRS-T-12-2009 (with latest amendment). The chosen manufacturers shall be required to submit their inspection and test plan for approval by Metro railway as per IRS-T-12-2009. Metro railways will ensure that the inspection and test plan approved by them strictly conforms to the requirement of IRS specifications.

4.2 Welding of rail:

4.2.1 The welding of rails should conform to Indian Railway specifications and technical instructions issued from time to time.

4.2.2 The present instructions are contained in following documents:

4.2.2.1 Alumino Thermit Welding:

(i) Indian Railway Standard specifications for Alumino Thermit Welding of Rails (IRS/T-19 with latest amendments)

(ii) Manual For Fusion Welding Of Rails By The Alumino-Thermic Process : Revised-2012 with latest amendments

4.2.2.2 Flash Butt Welding:

Manual for Flash Butt Welding of Rails, January 2012 with latest amendments.

4.2.2.3 Special attention is required by metros for provisions of these instructions regarding procurement, execution of works and areas requiring prior approval/ standardisation by RDSO.

4.3 Ultrasonic Testing of Rail and Welds:

The rails and welds shall be ultrasonically tested in field as per requirement of concerned specification/ manual/ instructions. The testing shall be ensured as per provisions of "Manual for Ultrasonic Testing of Rail and Welds- Revised 2012" with latest amendments. The provisions of "IRS specification for Ultrasonic testing of Rails/Welds (Provisional), Revised-2012" shall also be followed.

5. Sleeper and fastening for Ballasted track

5.1 Sleepers:

5.1.1 Broad Gauge

The PSC sleepers shall be used in accordance with RDSO drawing no. T-2496 and specification IRS-T-39 (revised from time to time).

5.1.2 Standard Gauge

PSC sleeper for standard gauge will be designed by Metro Railways following in principal guidelines of Indian Railway and the same shall be approved by Metro.

5.2 Fastening system:

The elastic fastening system prevalent on Indian Railways shall be used duly ensuring the Inspection protocol for fastening components laid down for IR.

In case of use of elastic fastening other than in use on IR, prior approval shall be obtained from Railways.

6. Track slab for Ballastless track

6.1 Track shall be laid on cast in situ/precast reinforced plinth or slab, herein referred to as the 'track slab'. The track slab shall be designed as plinth beam or slab type ballastless track structure with derailment guards. It shall accommodate the base plates of the fastening system.

6.2 In general, track slab (including sleeper, if any) on which the fastening and rail are to be fitted shall perform the following functions:

i) Resist the track forces. (Static and dynamic)
ii) Have adequate edge distance of concrete beyond the anchor bolts to provide resistance against edge failure
iii) Provide a level base for uniform transmission of track/rail forces.
iv) Have geometrical accuracy and enable installation of track to the tolerances laid down.
v) Ensure drainage.
vi) Resist weathering.
vii) Be construction friendly, maintainable and quickly repairable in the event of a derailment. The 'Repair and Maintenance methods' shall be detailed in a Manual to be prepared and made available.
viii) Ensure provision for electrical continuity between consecutive plinths/slabs by an appropriate design.

ix) Plinth beam or slab of ballastless track should be suitable for embankment or viaduct or tunnel/Underground structure.
x) Proper design of expansion joints suitable for joints of viaduct structure.
xi) Design should be suitable for curves as per SOD of Metro system.
xii) Design of subgrade/embankment for slab should be furnished to ensure durability and functional stability in service.
xiii) Design should be suitable and incorporate provision of utilities e.g. cable, wires, ducts, water channels, etc.

The detailed design calculations of track slab along with detailed structural drawings as approved by metro authorities shall be furnished for record.

7. Check Rail / Restraining Rail:

7.1 Check rails/ Restraining Rails should be provided on curves on main line where radius is 218m or less on Broad gauge and radius is 190m or less on Standard gauge. The clearance of check rail/ restraining rails shall be suitably decided after requisite studies. The detailed design calculations/ studies in this regard shall be furnished for record.

7.2 Check rails/ Restraining Rails shall not be mandatory for curves in depots, yards and non-passenger lines where speed is not more than 25 kmph. However decision in this regards may be taken by Metro themselves based on layout and maintenance requirement.

8. Derailment Guards

8.1 The derailment guard should be provided inside/outside of running rail on viaduct as well as in tunnel having multiple tracks and at grade section locations specified by the Metro railway. For single track tunnel, location for providing derailment guard is given in note. In tunnels, the derailment guard should preferably be provided inside the track, so that it permits less sway of coach towards tunnel wall in case of derailment.

NOTE:

Location for providing Derailment Guard in single track tunnel

1. Entry of tunnel: 200 m from tunnel portal outside the tunnel to 50 m inside the tunnel.
2. Exit of tunnel: 50 m from inside of tunnel portal to 200 m outside the tunnel.
3. In curved track having radius 500 m or less including transition portion but excluding locations where check rail is provided.
4. Covering locations of all important installations e.g. Location of any sub-station or hazardous structures inside the tunnel, etc damage to which in the assessment of metro rail administration can result into serious loss of life or/and infrastructure as a result of derailment in tunnel.

The above is subject to the condition that metro railway shall carry out the risk assessment analysis for derailment in tunnels and ensure that the maintenance practices in the maintenance manual are as per the risk assessment mitigation plan.

8.2 The lateral clearance between the running rail and the derailment guard shall be 210 ±30 mm. It shall not be lower than 25 mm below the top of the running rail and should be clear of the rail fastenings to permit installation, replacement and maintenance.

8.3 Derailment guard shall be designed such that in case of derailment:

(i) The wheels of a derailed vehicle under crush load, moving at maximum speed are retained on the viaduct or tunnel.

(ii) Damage to track and supporting structures is minimum.

The detailed design calculations of derailment guards along with detailed structural drawings shall be furnished for record.

9. Glued Insulated Rail joint

9.1 Normally glued joint should be avoided.

9.2 Wherever inescapable, G3 (L) type of glued insulated rail joint shall be used as per RDSO drawing no.T-5843. The glued joints shall be manufactured and tested in accordance with RDSO's 'Manual for Glued Insulated Rail Joints-1998' with all amendments.

10. Turnouts, Scissors Crossover

10.1 Standards of Turnout:

10.1.1 Main lines:

On main lines, the turnouts and diamond crossing shall be of the following standards:

(i) Standard Gauge

a) 1 in 9 type or flatter turnout (desirable)

b) 1 in 7 type turnout (minimum)

c) Scissors cross-over of 1 in 9 / 1 in 7 type consisting of 4 turnouts and 1 diamond crossing

(ii) Broad Gauge

a) 1 in 12 type turnout

b) 1 in 8.5 type turnout

c) Scissors cross-over of 1 in 12 type consisting of 4 turnouts and 1 diamond crossing

10.1.2 Depots and Non running lines:

On depot and other non-running lines, the turnouts and diamond crossing shall be of the following standards:

(i) Standard Gauge

a) 1 in 7 type or flatter turnout

b) Scissors crossover of 1 in 7 type consisting of 4 turnouts and 1 diamond crossing

c) 1 in 7 derailing switches/1 in 7 type symmetrical split turnout

(ii) Broad Gauge

a) 1 in 8.5 type turnout

b) Scissors cross-over of 1 in 8.5 type consisting of 4 turnouts and 1 diamond crossing

c) 1 in 8.5 derailing switches /1 in 8.5 type symmetrical split turnout

10.1.3 If any Metro railway decides to use sharper angle layout, they should establish the adequacy of the speed potential of the turnout for the purpose for which it is used and the negotiability of the turn out by the rolling stock with a safety margin.

10.1.4 The requirement for turnouts as specified in the following clauses shall include switch devices, crossings and associated check and lead rails as appropriate.

(a) Turnouts (switches, lead, crossings and associated closure & check rails) shall be suitable for installation on PSC sleepers for ballasted track or concrete slab for ballastless track.

(b) Turnouts shall be manufactured to allow for installation of continuously welded track.

(c) Turnout shall be compatible with proposed rolling stock and its operational characteristics.

(d) The assembly must ensure continuous electrical contact with the train and all the points shall be operated by electric motors.

(e) The CMS crossing to be used on mainline shall be subjected to explosive hardening.

(f) All turnouts shall be laid with cant with a rail slope as that of main line towards centre of track.

(g) All turnouts and their components shall be designed to minimize electrical leakage from running rails to the ground.

(h) Scissor crossover should be designed for Track centres not infringing SOD.

10.2 Type and geometry of turnout

Detailed design of all turnouts, scissors, and crossover should comply the following geometrical parameters.

(a) Standard Gauge

(i) 1 in 9 turnout:

The design shall be tangential with a switch angle not exceeding 0°20'00''. It is desirable that the radius of lead rail of turnout is not less than 300m. Lead curve of 190 m radius may be laid as an exception. All clearances shall be in accordance with relevant provisions of SOD.

(ii) 1 in 7 turnout:

The design shall be tangential with a switch angle not exceeding 0°20'00''. It is desirable that the radius of lead rail of turnout is not less than 190m. Lead curve of 140 m radius may be laid as an exception. All clearances shall be in accordance with relevant provisions of SOD.

(iii) Scissors Crossover

The basic geometry of the turnouts of scissors crossover shall be same as that of corresponding ordinary turnouts as mentioned in clause 10.2 (i) (ii) above.

(b) Broad Gauge

(i) 1 in 12 turnout

The design shall be tangential with a switch entry angle not exceeding 00 20'00''. The radius of lead rail of turnout shall not be less than 410m. All clearances shall be in accordance with relevant provisions of SOD.

(ii) 1 in 8.5 turnout

The design shall be tangential with a switch entry angle not exceeding 00 20'00''. The radius of lead rail of turnout shall not be less than 218m. All clearances shall be in accordance with relevant provisions of SOD.

(iii) Scissors Crossover

The basic geometry of the turnouts of scissors crossover shall be same as that of corresponding ordinary turnouts as mentioned in clause 10.2 (iv) & (v) above.

10.3 Operating requirement of turnout, scissor crossover:

Track layout design shall permit trains to operate at maximum capability wherever possible. Turnouts and crossover shall be selected such that they do not form a restriction to the operating speed on main line. Switches and crossings shall not be located on transition curves or vertical curves.

10.3.1 Speed: The turnout shall be designed for the speed on mainline side equal to the speed as on mainline track. The minimum speed potential of the various turnouts and scissors crossover on the Turnout side should be as follows:

10.3.1.1 Standard Gauge

(i) 1 in 9 type turnout with 300 m radius (speed potential of 45Kmph)

(ii) 1 in 7 / 1 in 9 type turnout with 190 m radius (speed potential of 35Kmph)

(iii) 1 in 7 type turnout with 140 m radius (speed potential of 25 Kmph)

(iv) Scissors crossover 1 in 9 type with 300 m radius (speed potential of 45 Kmph)

(v) Scissors crossover 1 in 9/1 in 7 type with 190 m radius(speed potential of 35Kmph)

(vi) Scissors crossover 1 in 7 type with 140 m radius(speed potential of 25 Kmph)

(vii) 1 in 7 type symmetrical split turnout (speed potential of 45Kmph)

10.3.1.2 Broad Gauge

(i) 1 in 12 type turnout (speed potential of 50Kmph)

(ii) 1 in 8.5 type turnout (speed potential of 30Kmph)

(iii) Scissors crossover 1 in 12 type (speed potential of 50Kmph)

(iv) Scissors crossover 1 in 8.5 type (speed potential of 30Kmph)

(v) 1 in 8.5 type symmetrical split turnout (speed potential of 40Kmph)

10.4 Technical Specification

10.4.1 General

(a) All the points shall be capable of being operated by electric motors in accordance with the signalling specification.

(b) The top surfaces of PSC sleeper/RCC slab supporting rail seat of turnouts and scissors crossover shall be flat without any cant/slope.

(c) The track form of the turnout shall have uniform resilience as that of the adjoining track form.

(d) The fixation of turnouts, scissor cross-over on track slab shall be through base plates/bearing plates.

10.4.2 Rails

1. The rails used in turnouts shall be 1080 grade Head Hardened. However, rails used in turnouts on depot and other non-running lines may be of 880 grade.
2. The rails used for manufacturing of turnouts shall satisfy the following conditions:
    a. The rails shall be manufactured and tested in accordance with IRS/T-12-2009 with latest amendment.
    b. The section of rails shall be 60E1 (UIC60) for stock, lead and 60E1A1 (ZU1-60) /60E1A4 for switch rail.
    c. The rails shall qualify as Class 'A' rails as per IRS/T-12-2009.
    d. The rails shall be with ends un-drilled.
    e. The rails shall be of grade 1080HH and be suitable for being welded by alumino-thermic or flash butt welding technique.

10.4.3 Switches

1. Each switch device shall consist of two stock rails, one left hand and one right hand and two switch rails, one left hand and one right hand.
2. The switch rail shall be one piece with no weld or joint within the switch rail length.
3. The end of the asymmetrical switch rail shall be forged to 60E1 (UIC60) rail profile with minimum length of 500 mm. The forged switch rail end shall be suitable for welding or installation of insulated rail joint.
4. Slide chairs in the switch portion shall be coated with an appropriate special coating, so as to reduce the point operating force and to eliminate the requirement of lubrication of sliding surfaces during service.
5. Switches shall provide suitable flange way clearance between the stock rail and the switch rail with the switch rail in open position (minimum 60mm). The 1 in 12 and 1 in 9 (with radius of 300 mts) and flatter turnouts shall be provided with second drive or other suitable arrangement to ensure minimum gap of 60mm at JOH as well as proper housing of switch rail with stock rail up to JoH. 1 in 8.5, 1 in 9 turnout (with radius of 190m) and 1 in 7 and sharper turnouts may not be provided with second drive arrangement, however minimum gap of 60mm at JOH as well as proper housing of switch rail with stock rail up to JoH should be ensured. The normal opening of switch at toe of switch shall be kept as 160mm.
6. The switch manufacturer shall include provision for all holes required to main drive machines, stretcher bars and detection equipment to suit the requirements of the signalling and switch operating system duly chamfered to avoid stress concentration at the edge of the holes.

7. The switches shall be designed with an anti-creep device at the heel of switch to withstand thermal forces of the CWR track.
8. The switches and all slide chairs shall be same for ballasted and ballastless turnouts.

10.4.4 Crossings

1. All crossings shall be cast manganese steel (CMS) crossings with weldable rails of minimum 1.2m length undrilled for welding into the overall turnout.
2. The CMS crossings shall be manufactured from Austenitic Manganese steel as per UIC 866.
3. All CMS crossings shall have welded leg extensions of 60E1 (UIC60) rails. This shall be achieved by flash butt welding of buffer transition rail piece of suitable thickness to CMS crossings and rail leg extension.
4. All CMS crossings on main line shall have a minimum initial hardness of 340 BHN.
5. All CMS crossings and their welded leg extensions for all scissor crossovers shall be suitably dimensioned so as to eliminate the necessity of providing small cut rail pieces for the purpose of inter-connection. However, the need for providing insulated glued joints from signalling requirement point of view shall be taken care of in the design, if required.
6. The provision of rail cant shall be taken care of on the top surface of the CMS crossing and the bottom surface of all CMS crossing shall be flat.

10.4.5 Check Rails

1. The check rail section shall be 33C1 (UIC33) or similar without any direct connection with running rails.
2. Check rails shall have the facility for the adjustment of check rail clearances up-to 10mm over and above the initial designed clearance.
3. Each check rail end shall be flared by machining to have minimum clearance of 62mm at end.
4. The check rail connections in turnouts shall be through specially designed bearing plates / brackets.
5. All the check rails shall be higher by 25mm above running rails. The lengths and positions of the check rail in diamond crossings shall provide safety and be compatible with the overall track layout.

10.4.6 Sleeper for Turnouts, Scissor crossover (Ballasted Track)

10.4.6.1 Sleeper shall be of pre-stressed concrete, mono-block, suitable for installation in track both with and without signalling circuits and with and without electrification.

10.4.6.2 Sleepers shall be designed to provide a minimum service life of fifty years under nominal axle load as that of main line for the Metro system. Rail seat pads and rail clip etc shall be designed to provide a minimum service life of 15 years.

10.4.6.3 The sleeper base surface shall be rough cast while the top and side surface shall be smooth to prevent retention of moisture and foreign materials.

10.4.6.4 Sleepers must be suitable for installation by track laying machines and sleeper insertion equipment of a type used for isolated sleeper laying.

10.4.6.5 The sleeper must be able to transfer all the relevant track forces generated by train operations and the forces of rail expansion and contraction to the ballast.

10.4.6.6 Design Requirements for PSC Sleepers:

(A) The sleepers should satisfy the following design requirement:

Design Parameters

(i) Rail sleeper fastening – Elastic resilient type
(ii) Spacing of sleepers – 600mm (max) for main line and 650 mm (max) for Depots and other non-running lines, except at few locations such as near point machine locations where it may be varied to meet the design requirements.
(iii) Ballast cushion – 300 mm for mainline and 250mm for Depots and sidings
(iv) Ballast profile suitable for LWR/CWR.

Specifications and Drawings (With latest amendment)

(i) Special Cement – IRS T 40 1985
(ii) HTS wire plain and strand – BIS – 1785 (Pt-1) 1983 and BIS 6006
(iii) Polyethylene dowels – Provisional 1997 Drg. No. RDSO 3002 Alt-3
(iv) IRS Specification for Turnout Sleeper T- 45 1996
(v) IRS Bridge code 1982
(vi) Code of Practice for Pre-stressed Concrete IS-1343

(B) The design should satisfy the following additional requirements-

(i) The connections of the slide chairs and bearing plates/special bearing plates/brackets shall be designed for easy installation and maintenance. All the fittings shall be suitably designed to ensure full compatibility & also to ensure interchangeability of slide chairs between ballasted and ballastless turnouts.

(ii) For attaining suitable cant of the rail, as provided on mainline, (excluding crossing and switch portion), suitably designed pads of appropriate material shall be provided between rail pad & PSC sleeper. Also fastening system should be designed to get the desired Toe Load.

(iv) The detailed design of Monoblock PSC sleepers for the turnouts along with structural drawings shall be checked and approved by metro railways.

11. Switch Expansion Joint-

1. The SEJ for ballasted track shall be laid on PSC sleepers whereas the SEJs for ballastless track, if required, shall be laid on reinforced concrete slab.
2. The rail section for all SEJs shall be UIC 60, 1080 HH grade as per IRS-T-12-2009.
3. The SEJ for ballasted track shall be designed for a maximum gap of 80 mm.
4. The SEJ for ballastless track should be designed for the maximum gap required as per design.
5. The ballasted SEJ shall be as per RDSO drawing T-6902 &T-6922.

6. The ballasted SEJ for BG shall be laid with PSC sleepers as per RDSO drawing T-4149. For Standard Gauge, PSC sleeper shall be designed such that SEJ to RDSO drawing along with its bearing plates/chairs may be accommodated for installation of SEJ.
7. Sleepers used for SEJs shall be flat and cant will be provided through CI chair.
8. The SEJ shall be suitable for two way directional traffic.

12. Fastening system for ballastless track:

Provisions contained separately in "PERFORMANCE CRITERIA OF FASTENING SYSTEM FOR BALLASTLESS TRACK ON METRO RAILWAYS/MRTS SYSTEM" (Annexure C-2) be referred to.

13. Noise and Vibration

Metro system shall be designed to ensure that noise emitted is well within the prescribed limits for the particular area. Each Metro system shall specify the prescribed limits of permissible Noise and vibration parameters as per legal and statutory requirement of India.

14. GRADIENTS

14.1 The maximum grade (compensated) shall be 4%.

Note:

(i) There will be no change of gradient in transition portion of curves.

(ii) The gradient will be compensated for curvature at the rate of 0.04% per degree of curve.

14.2 Maximum permissible gradient on turnouts

(i) On Ballasted Track 0.25%

(ii) On Ballastless Track 2.5%

Note :

(i) There shall be no change of grade on and within 15m of any turnout on ballastless track. Similarly, there shall be no change of grade on and within 30 meters of any turnout on ballasted track.

(ii) In case of turnouts on gradient, there shall be no horizontal curve on and within 15 meters of any turnout on ballastless track and 30 meters of any turnout on ballasted track.

14.3 TRACK GRADIENT IN PLATFORM

(a) Maximum 1 in 400

(b) Desirable Level

Note: There shall be no change of gradient in platform track.

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Part-B: Salient features of Track Structure as adopted by Metro

i) Track

s.no.	Components / Items	Provisions / Reference
1.	Gauge	
2.	Axle Load	
3.	Design Speed	
4.	Rail Section and Grade	
5.	Rail Specifications	
6.	Ballasted or Ballastless	
7.	Rail inclination (Canting of Track)	
8.	Check Rails provision	
9.	Provision of Derailment upstand/Gaurd	
10.	Horizontal Clearance of Derailment upstand	
11.	Vertical location of Derailment upstand w.r.t. Rail plane	
12.	Glued insulated Rail Joint provided? If Yes , type of GIRL	
13	Welding Of Rail (LWR /CWR)	
14	Whether SEJ provided? If Yes Type of SEJ	
15	Type of welding	

ii) Turnouts and switches:

S.N.	Components / Items	1	2	3	4
1	Type of turnout , scissors crossovers (crossing angle)				
2	Canted or uncanted				
3	Radius				
4	Length of switch				
5	Type of Switch (Thick web or otherwise)				
6	Switch entry angle				
7	Speed potential				
8	Location of Use (Main line or Depot)				
9	Rail Section used for switch				
10	Second drive provided				

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iii) Crossing:

	Components / Items	Provisions / Reference
1.	Crossing: Curved or Straight	
2.	Crossing: Canted or uncanted	
3.	Length of Weldable length extension	
4.	Check Rail section	
5.	Height of Check rail above the rail plane	
6.	Check Rail clearance at the middle	
7.	Check Rail clearance at the end	

Part-C: Check List of submissions while submitting compliance:

1	Compliance of Part-A	
2	Design of subgrade/embankment for slab (Para 6.xii)	
3	Design calculations of track slab /plinth beam along with detailed structural drawings as approved by metro authorities. (Para 6)	
4	Design calculations/ studies with regard to clearance of Check rails/ Restraining Rails. (Para 7.1)	
5	Design calculations of derailment guards along with detailed structural drawings shall be furnished for record. (Para 8)	

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Part-A: Performance criteria of fastening system for ballastless track on Metro Railways/MRTS system (Compliance to be given)

1. **Purpose and Selection:**

1.1 The performance criteria define the performance standard of fastening system for ballastless track of Metro Railway System. Apart from other things, the fastening system is required to moderate vibration and noise transmitted through the rail and to reduce the track stiffness and the impact on the track structure, so as to obtain the parameters as detailed in the ensuing paragraphs.

1.2 A new fastening system, which is fully compliant to performance criteria and not approved by MoR can also be used by Metro Railways/MRTS system as they are free to choose fastening systems for ballastless track complying with this performance criterion. The detail of such fastening system used shall be submitted to MoR and the same shall be kept in observation by MoR for a period of 2 years under service conditions in association of Metro Railways/MRTS system. The Performa for the monitoring performance shall be advised by MoR to concerned Metros Railways/MRTS system. After successful performance for 2 years, Metro Railways/MRTS system shall process for approval of MoR for further use of fastening system.

1.3 The fastening system already approved by MOR as per previous performance criteria for ballastless track dated 21.5.2010 will not require fresh clearance as per this revised criteria and any of these systems can be used by Metro/ MRTS systems.

1.4 In case Metros Railways/MRTS system opts for a new fastening system for ballastless track which is not fully compliant to these performance criteria, they will approach MoR for approval before finalizing the use of fastening system.

2. **Operating Environment:**

Fastening system is expected to perform generally in the following conditions:

2.1 Gauge –Broad Gauge, 1676/1673mm (nominal) and standard gauge – 1435mm
2.2 Speed potential – 110 kmph(max.)
2.3 Rail section - 60kg(UIC)/60E1, 90 UTS/110 UTS
2.4 Static axle load – BG & SG – 20t(Max)
2.5 Design rail temperature range – 10 degree Celsius to +70 degree Celsius
2.6 Curvature and gradient will be specified in SOD.
2.7 Rail seat inclination (slope) – 1 in 20

In addition, the client Railway may specify any other operating condition such as support spacing etc.

3. **Ballastless Track Structure:**

Track shall be laid on cast in situ/pre-cast reinforced plinth or slab, herein after referred to as the 'track slab'. The track slab shall be designed as plinth beam or slab type ballastless track structure with derailment guards. The track slab dimensions and the clearance between rail and derailment guard shall be sufficient to accommodate the base plates of the fastening system and to facilitate easy and convenient replacement of the fastening system. The clearance between rail and derailment guard shall be within the range provided in Annexure-C-1.

In general, track slab on which the fastening and rails are to be fitted shall:

i) Resist the track forces.
ii) Have adequate edge distance of concrete beyond the anchor bolts to provide resistance against edge failure.
iii) Provide a level base for uniform transmission of rail forces.
iv) Have geometrical accuracy and enable installation of track to the tolerances laid down.
v) Ensure adequate drainage
vi) Resist weathering
vii) Be construction friendly, maintainable and quickly repairable in the event of a derailment. The 'Repair and Maintenance methods' shall be detailed in the 'Track Maintenance Manual' to be prepared and made available before the line or a portion of a line is opened for traffic .
viii) Ensure provision for electrical continuity between consecutive plinths/slabs by an appropriate design.

4. Performance Requirement of Fastening System:

4.1 General

i) The fastening system shall be designed to hold the two rails of the track strongly to the supporting structure in upright position by resisting the vertical, lateral and longitudinal forces (including thermal forces) and vibrations.

ii) The fastening shall be with a proven track record. The fastening system should have satisfactory performance record of minimum three years in service in regular revenue operation on ballastless track on any two different established railway systems (except exclusive freight tracks) for a length of at least 5km in each metro having speed potential of at least 80 kmph & design axle load 16T irrespective of wheel profile and rail section. In this regard, supplier should submit certificate of performance from user railways administration including proof of use of the fastening system. The supplier has also to submit a certificate that the components of fastening assembly are having same material and specification in case the proven system is having different rail section and wheel profile along with details of test results as per test plan of Table 1.

Note: For any metro system having design axle load <16T, the above criteria shall be applicable for the axle load for which the metro system is designed."

iii) The fastening shall provide insulation to take care of return current of traction system.

iv) Fastening should satisfy the required performance norms as stated in para 4.2, 4.3, 4.4, 4.5,& 4.6.

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4.2 Following are the technical performance requirements of fastenings:

The Fastening shall

i) Have design service life of 30 years in general. However, its components such as rubber pad, rail clip etc. can be designed for 300 GMT or 15 years whichever is less. Anchor bolts or studs used for fixing base plate to the concrete should not be required to be replaced during service life. Its components must not suffer any degradation during service life to a degree so as to affect the performance and safety of the track. Full service life is to be attained under the following conditions:
   a) Atmospheric ultra violet radiation.
   b) Proximity of track up to 10m from salt water source.
   c) Contact with oil, grease or distillate dropped from track vehicles.

ii) Permit quick and easy installation and replacement with special tools.

iii) Be capable of vertical adjustment during service life upto 12mm using shims.

iv) Permit the attainment of the following tolerances when installed, and later during service.

Sl	Parameter	Installation (mm)	Maintenance (mm)
1	Gauge	+2,-1	+4,-2
2	XL on straight track	±1.5	±5
3	SE on curved track	±1.5	±3
4	Vertical alignment over 20m chord	±3	±6
5	Lateral alignment over 20m chord on straight track	±2	±6
6	On curves-variation over the theoretical versine on 20m chord	±2	±5

4.3 Anchor bolts/studs used for fixing the bearing plate in concrete shall have splayed ends. Detailed calculations for the number of anchor bolts required on tangent and curved tracks shall be furnished by the supplier and approved by the Metro system

4.4 For all the fastening components as per approved assembly, the supplier shall furnish detail drawings, specifications and inspection& test plan to the Metros. Metros to ensure that components are supplied as per drawings & specifications..

4.5 The supplier should furnish the 'Installation and Maintenance Manual' which shall be approved by the Metro system.

4.6 Any change in component subsequent to the approval of the fastening system by MoR shall be permitted only for specific requirement of the metro. MoR approval of such changes shall be processed by metro with specific recommendations enclosing test report of the component / whole assembly with detailed justification.

4.7 The rail fastening system shall be tested to the following specifications (Table 1) for different technical parameters and should meet the acceptance criteria as mentioned in the following table. Test report of the reputed independent institute / laboratory will have to be submitted. The testing is to be done for Cat B as specified in EN-13481-Part-I 2012 & EN-13481-5 :2012 with rail section to be used in proposed system if other design particulars are meeting the requirement of Cat –B.

Table-1

Test Plan for Fastening system (bonded & non bonded) for Ballastless Track

(As per provisions of latest EN 13481-1:2012 & EN 13481-5:2012)

S.N.	Technical Parameters	Test Method	Acceptance criteria	Remarks
1	Longitudinal rail restraint	EN-13146-1-2012	7kN (min)	This has to be tested before repeated load test
2	Vertical static stiffness of complete fastening assembly	EN-13146-4-2012	35 kN/mm (max)	No sliding, yield or cracking is allowed for the fastener parts.
3	Dynamic/static stiffness ratio	EN 13481-5-2012	1.4 (max)	Ratio is calculated by dividing the dynamic stiffness to static vertical stiffness.
4	Clamping force	EN-13146-7-2012	18kN (min) Perrail seat	This has to be tested before repeated load test
5	Electrical resistance	EN-13146-5-2012	5kΩ (min)	Higher value may be specified if required by Metros for track circuit
6	Effect of severe environmental conditions	EN-13146-6-2012	The fastening assembly shall be capable of being dismantled, without failure of any component & reassembled using manual tools provided for this purpose after exposure to the salt spray test.	-
7	Effect of repeated loading	EN-13146-4- 2012	No wear or deformation	-
7A	On Vertical static stiffness	EN-13146-4- 2012	Variation ≤ 25% of the initial value	No sign of bond failure/ fracture/slippage
7B	On Longitudinal rail restraint	EN-13146-1- 2012	Variation ≤ 20% of the initial value	Except the rail and fastener, no sliding, yield or cracking is allowed for fastener

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S.N.	Technical Parameters	Test Method	Acceptance criteria	Remarks
				parts. Longitudinal load/ deformation curve shall fall in the envelope of upper and lower limit which is to be submitted along with the report.
7C	On Clamping force	EN-13146-7-2012	Variation ≤ 20% of the initial value	-

Part-B: Salient features of Fastening System

S.N.	Components / Items	Provisions in Metro
1.	Brief description of fastening system	
2	Axle load	
3	Speed potential	
4	Drawing and their numbers	
5	Specifications and their numbers	
6	Any variation for straight and curve portion? If yes, give detail	
7	Vertical stiffness of complete fastening system	
8	Service life of fastening system.	
9	Reference of Railway Board's approval for proposed fastening system.	

Part-C: Check List of submissions:

1	Compliance of Part - A	
2	Sets of drawings (two numbers)	
3	Performance record of fastening system	
4	Test report of fastening system.	

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Documents required for record for traction (OHE) and Power Supply System at appropriate stage.

1. Details of General Arrangement of OHE duly approved by Metro Authorities.

   General arrangement Drawing pertaining to the followings:

   a) Catenary Wire, Contact Wire, Aerial Earth Wire, Buried Conductor, Buried Rail, Booster Transformer, Return Conductor.
   b) Cantilever Assemblies, Droppers, Schedule, Jumpers.
   c) Insulated Overlaps, Un-insulated Overlaps.
   d) Turnouts & Crossover arrangements.
   e) Anti-Creep Arrangement. Termination, Anchoring Arrangement (along with Auto Tensioning Device).
   f) Feeding and Sectioning Arrangement including Traction Feeding Diagram.
   g) Position and details of Neutral Section.

2. Basic Design Data approved by Metro Authorities related to followings.

   a) Pre-sag of Contact Wire at mid-point.
   b) Gradient of Contact Wire (Relative and Absolute).
   c) Tension length, Spans, Stagger.
   d) Height of Contact Wires in Tunnels Bridges and in Open Routes.
   e) Wind Load & Seismic zones.
   f) Electrical Clearances (Longitudinal/ Lateral & Vertical - Static & Dynamic).
   g) Sweep zone of Pantographs & Panto pressures.

3. Design Details approved by Metro Authorities related to following:

   a) Typical Drawing of OHE at Support i.e. at Mast, Portal etc.
   b) Earthing Drawings for Viaduct/Tunnel (Typical).
   c) Earthing Design for Receiving/Auxiliary Sub-stations (RSS & ASS) (Typical).
   d) Typical Drawing of Cantilever Arrangement for Single Bracket, Multiple Bracket and Fittings.
   e) Make wise Drawing of Stay Insulator, Bracket Insulator, Tensioning Insulator, Disc Insulator, Section/ Core Insulator, Post Insulator, Operating Rod Insulator. (These are one time design and are not repeated for every project/section. Specifications showing Electro-mechanical characteristics can be submitted once for every Project).
   f) Conceptual Drawing for traction Return Current including longitudinal continuity and integral transfer links.
   g) Design Calculations, Simulation, Drawings for Earthing and Bonding (including Earth Conductors and connection).
   h) Simulation report of Electromagnetic Interference current including the effect of Booster Transformer and Return Conductors.
   i) Detail of Feeder Protection

      (i) Protection of Phase Gaps/Neutral Sections,

(ii) Extension of Power in case of emergency

4. Details of Power Supply Arrangement duly approved by Metro Authorities related to followings:

   a) EIG application with following:
      i. Details of Power Drawl from the Power Grid.
      ii. General Arrangement Details of Sub-stations
      iii. Protection Philosophy and relay setting calculations.
      iv. Earthing Arrangement for the Power Supply Installations (Traction/ Non-Traction Power Transformer, Switching Posts).
      v. Equipment details.
   b) Power Supply Simulation with Electric Loads for peak traffic and under extended feed conditions.
   c) Sizing of Transformers, Conductors, Bus-bars, Instrument Transformers.
   d) Details of Insulating Oils along with their class and technical details.
   e) References for proven-ness of various Assemblies/ Sub-assemblies/ Equipments used in Overhead Traction Equipment.

5. EIG Report.

6. Conceptual scheme of Supervisory Control and Data Acquisition System.

7. Safety Circulars, Procedures for grant and cancellation of Permit to Work.

8. Submission of test Certificates of Equipments:-
   a) Type Test of Insulators,
   b) Type Test of Contact & Catenary Wire,
   c) Type test of Booster Transformer, if any.
   d) Type Test of Traction Transformer,
   e) Type Test of Protection Relays,

ANNEXURE-D-2

Documents required for record for third rail traction system and Power Supply System at appropriate stage.

1. Details of General Arrangement of Third Rail Traction System duly approved by Metro Authorities. General arrangement drawing pertaining to the following:
   a) Third Rail,
   b) Bridgeable & Non-Bridgeable Gaps,
   c) Third Rail Ramps at Turnouts,
   d) Mid Point Anchor,
   e) Expansion Joints,
   f) Insulated Joints (IJ),
   g) Third Rail Brackets,
   h) Power Feed Assemblies,
   i) Splice Assemblies,
   j) Vertical & horizontal clearances of Third Rail,
   k) Feeding and Sectioning Arrangement including Traction Feeding Diagram.

2. Basic Design Data approved by Metro Authorities for the followings:
   a) Third Rail Characteristics, Material & Electrical Properties,
   b) Third Rail current carrying capacity & Temperature Rise,
   c) Electrical resistance,
   d) Peak Current Temperature Rise,
   e) Short Circuit Level,
   f) Third Rail Bracket Spacing,
   g) Horizontal & Vertical Clearances of Third Rail,
   h) Shroud for Third Rail,
   i) Third Rail mounting insulator.

3. Design Details for Third Rail System approved by Metro authorities should also be given for records as under:
   a) Design calculations of Third Rail, Bracket, Insulated Joints, Expansion Joints, Ramps, Third Rail current carrying capacity & Temperature Rise
   b) Thermal Expansion,
   c) Conductor Rail Deflection,
   d) Bracket Loading Calculations,
   e) Bracket mechanical Validation,
   f) Bracket Welding Validation,
   g) Design Calculations for traction Return Current,
   h) Design Calculations for Earthing and Bonding for Receiving Substation, Traction Substation and Auxiliary Substation Calculations of Electromagnetic Interference / Electro Magnetic Compatibility,
   i) Bridgeable & Non-Bridgeable Gaps,
   j) Extension of power in case of emergency.

4. Details of Power Supply Arrangement duly approved by Metro Authorities for the following:

a) Details of Power Drawl from the Power Grid.
b) General Arrangement Details of Sub-stations. Documents shall adhere to latest Indian Electricity Rules & Statutes in force.
c) Protection Philosophy, Engineering Details along with calculations for High Voltage Circuits, Low Voltage Circuits and Transformers which shall include Traction and non-Traction loads.
d) Power Supply Redundancy for all loads (Traction and Non-Traction Loads)
e) Earthing Arrangement for the Power Supply Installations (Traction/ Non- Traction Power Transformer, Switching Posts.)
f) Earthing, Bonding and Stray current mitigation, monitoring and control
g) Philosophy, Stray Current Control, EMC Validation Arrangement for Power Supply Installations (Traction/Non Traction Power Transformation, Switching Posts.)Power supply Simulation with Electric Loads for peak traffic and under extended/diverted Feed.
h) Power supply Simulation/Calculations with Electric Loads for peak traffic and under extended/diverted Feed as case to case basis.
i) Short Circuit Levels unbalance, Voltage Drop Calculations.
j) Sizing of Transformers, Conductors, Bus-bars, Instrument Transformers, Surge Protection.
k) Details of Insulating Oils along with class and technical details.
l) Details of Auxiliary Power Distribution including transformation details from grid to point of consumption, layout of Auxiliary Power Lines, Redundancy and Protection.
m) References for proven-ness of various Assemblies/ Sub-assemblies/ Equipments used in Third Rail System.

5. EIG Report.

6. Details of Supervisory Control and Data Acquisition System.

7. Declaration of Safety Policy, Procedures for grant and cancellation of permit to work.

8. Submission of Type test certificates applicable to Third Rail system as under:
a) Third Rail including assembly and accessories,
b) Power Cable, DC Cable, Control Cable & Optical Fibre Cables,
c) Rectifier Traction Transformer,
d) Auxiliary Transformer,
e) DC Equipments (Rectifier, HSCB Panel, BY Pass Panel, Dis-connector Switch, Short Circuit Device at Sub Stations, Negative Return Panel),
f) Sandwich Bus-duct,
g) C&R Panels,
h) Switchgear Panels,
i) SCADA & Related Equipments,
j) Battery, Battery Charger, UPS,
k) Alternating Current Distribution Board and Direct Current Distribution.

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ANNEXURE - E1

Following Documents are required for various sub-systems of signalling, duly approved by Metro authorities at appropriate stage.

Following Documents are required for various sub-systems of signalling, duly approved by Metro authorities at appropriate stage.

1. Independent Safety Assessor's **assessment of vital signalling equipment like CBI, ATP, track detection system etc. (all the items being used for vital functions shall be covered). Regarding ATO & ATS if provided ISA** certification shall be done to required safety level as decided by metro.
2. Submission of the following:
   (a) Relevant system details as may be necessary to give full particulars of principle of Operations and safety features incorporated for CBI, ATP, Track Vehicle Detection etc. Including ATO/ ATS, if provided.
   (b) Report of EMI/EMC interface with rolling stock/traction, as applicable for track Detection, on-board and other related equipments.
   (c) Typical schematic of earthing/ bonding of signalling equipment.

   Final comments of RDSO regarding technical planning and safety shall be forwarded to Metro within 28 days, after the receipt of final sets of documents.

3. Verification and validation and certification by the ISA** of adherence to SIL-4 process from design to testing and commissioning stages of signalling system, including application data of vital equipment for the Signalling system. This shall include hazard analysis, its mitigation and acceptance of the same by competent authority for the concerned Metro Railway.

Note:

i. Documents listed in Sr. No. (1) & (2) shall not be required in case there is an extension to an existing fine incorporating no new type of signalling equipment.

ii. Also documents listed in Sr. No. (1) & (2) shall not be required-if an equipment having same hardware and software version and approved earlier by Railway board is already in use on any Metro in India, however, safety and operational performance shall be submitted by Metro authorities for the equipments from user of metro/railways who are using the same equipment.

iii. ** "Independent Safety Assessors (ISAs):

   a) After RDSO notifies a panel of approved ISAs, Metro Rail authorities shall select an ISA from the approved panel for their Metro systems.

   b) Till such time RDSO forms the panel of approved ISAs, Metro Railways shall submit the credentials of ISAs identified /appointed by them to RDSO for scrutiny."

Annexure-E2

PROVISIONS TO BE ADOPTED FOR SIGNALLING& TELECOMMUNICATIONS SYSTEMS

It may be noted that the given criteria is based upon systems already adopted by the existing Indian Metros. However, in case Metro Authorities are adopting a new technology, then the same shall be advised and in principle concurrence of RDSO should be obtained in principle.

Signalling systems

SN	Description	Minimum requirement
1.	Type of Signalling	Cab Signalling, CATC (ATP, ATO, ATS). ATP and ATS are essential, ATO is optional.
2.	Back up Signalling	Line side (CLS) at entry and exit at all interlocked stations.
3.	Interlocking	EI with built-in block working facilities
4.	Train control system	CATC(ATP, ATS, ATO optional)
5.	Type of Track Circuits	Coded Audio Frequency Track Circuits (AFTC)
6.	Point machine	
	i) For Main Line	i) Non-Trailable high thrust, high performance point machine
	ii)For Depot	ii) Trailable high thrust, high performance point machine
7.	Redundancy in cab equipment for ATP (Cab Sig.)	1+1(hot standby)

Telecommunication systems

SN	Description	Minimum requirement
1.	Tele communication	Integrated system with OFC, Train Radio, CCTV, Centralised clocks, PA system, with the additional provision that Train Display Boards at stations should also be integrated in the system. Regarding Train Radio system, it should be fully digital and duplex system, the standards may be chosen based on techno-economic considerations.
2.	Positive Train Identification	Provided with interface between ATS and Train Radio

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Annexure – F1

METHODOLOGY FOR OSCILLATION TRIALS

Oscillation trial is conducted on a new or modified design of rolling stock, which is proposed to be cleared for running on Metro track. The purpose of oscillation trial is, thus, acceptance of a railway vehicle by conducting dynamic behaviour tests in connection with safety, stability and quality of ride.

The conduct of Oscillation trials is, generally, guided by 'Policy Circular No.6' issued by Railway Board and Standing Criteria committee's report as applicable at the time of trial, along with the trial scheme given by the Design Directorate.

1. Test Train formation and Runs :

The test train shall consist of at least 1 unit/ consist having one prototype representative coach of each type. The oscillation trial runs shall commence from the provisional speed/speed as laid down in the speed certificate issued for trial and increased in increments up to maximum test speed or up till running is safe whichever is lower. The increase in speed will be authorized by the officer in charge of the trial on the basis of results of preceding runs.

The trial is conducted in empty and different loading conditions. Additionally, in case of Rolling stock with air springs, the trials are also conducted for air springs in inflated and deflated conditions.

2. Instrumentation:

Unless otherwise required by the design directorate, the free end bogie of the vehicle will be instrumented. The prototype will thus be the last vehicle, of each type, in the formation. The Test Vehicle will be instrumented by testing directorate as per the test scheme, if required by welding suitable plates at the required locations. The following Transducers may be used for the trial:

(1) Accelerometers
(2) Optical displacement Sensors/String Pot displacement Sensors/LVDT
(3) Pressure Sensors.
(4) Optical Speed Sensors/ Wheel pick up device.
(5) GPS.
(6) Inclinometers/Gyroscopes
(7) Any other transducers required for the trial.

3. Data Acquisition/ Analysis:

Data is acquired by using a Digital data acquisition system, connected to the transducers provided on the prototype vehicle as given in para 2. Band pass filter of 0.4-10 Hz of fourth order is used. RI is calculated for 200m blocks. Speed being constant, time taken for 200m for each speed is calculated and according samples are taken for RI evaluation. Sampling rate used is 200 samples /sec.

The following parameters are recorded/calculated for evaluation:

SN	Parameter	Conditions & method
1	Maximum vertical acceleration on Coach Body	Measured on Car Floor of Car body as near to bogie Centre as possible. Maximum value should not exceed the prescribed limit
2	Maximum Lateral acceleration on Coach Body	
3	Maximum Dynamic wheel Loading/ Unloading - ΔQ/Q ratio	Maximum value of loading/unloading, calculated from spring deflection, should not exceed the stipulated value.
4	Maximum Value of RI	Calculated on the basis of acceleration values recorded as above (SN-1 & 2) as per ORE C-116 para 2.1(2a) (using FFT method with Zero padding) , should not exceed the specified value
5	A general indication of stable running characteristics of the carriage as evidenced by the movement of the bogie on a straight and curved track, and by the acceleration readings and instantaneous wheel load variations/spring deflections.	
6	Damping factor	Using wedge of 18 mm thickness. For evaluation by design directorate
7	Bogie Rotation and Lateral Movement w.r.t Car body	By Measuring Lateral displacement between Bogie frame and Car body. Recording must establish that the bogie can move without undue constraints.
8	Safety of running	By measuring Lateral accelerations on Bogie Frame. Evaluation by simplified method as given in Para 10.1.3.1(4) of UIC-518 of October -2005
9	Derailment Coefficient (Y/Q) over a period of 1/20th second	*Derailment coefficient, if required, worked out in the form of ratio between the lateral force (Y) and the instantaneous wheel load (Q) continuously over a period of 1/20th second, measured by a measuring wheel.*
Note: 1. Safety certifications shall be done on the basis of tests at SN- 1 to 5 *and* 9, other tests are for investigation purposes only. **2.** As per decision by Inter-Ministerial Committee item no. 9 is to be reviewed by the Criteria Committee of RDSO		

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Band pass filter of 0.4-10 Hz is used. RI is calculated for 200m blocks. Speed being constant, time taken for 200m for each speed is calculated and according samples are taken for RI evaluation. Sampling rate used is 200 samples /sec.

4. Facilities to be made available by Metro:

The Metro shall make the following facility available for conducting of trial:

(i) Competent Crew for operating the Test Special.

(ii) Prototype test rake, made suitably fit for trial, for instrumentation and trial runs.

(iii) 220V AC Power supply on board the test special.

(iv) Instrumented Measuring wheel, if required.

(v) Facility for fixing/mounting for instrumentation, including Welding equipment and manpower, if required.

(vi) Any other facility as required by the officer in charge of the trial for the conduct of the trial.

Annexure-F2

CRITERIA FOR OSCILLATION TRIALS OF METRO ROLLING STOCK

1.0 SELECTION OF TEST TRACK

1.1 For new metro system, oscillation trial shall be done over the complete section before introduction of first train; and over any new section that is subsequently added to the system if the new section includes:

a) A tangent (straight) track of 1 km if the earlier trial had been conducted on less than this length.

b) Curves sharper than that available in the section covered during an earlier trial or a curve of 2° of about 700-800 m length, if the earlier trial had been conducted on less than this length.

c) Turnout or crossover, if the earlier trial had been conducted without it or with a flatter one.

For introducing a new stock over the existing sections, trial shall be done over

a) The longest tangent (straight) track subject to a maximum of about 1 km length. Trial shall be conducted over two stretches, if available.

b) A Curve of 2° if available, preferably of about 700-800m length and the sharpest curve available in the system.

c) A station yard having turnout or crossover, if available, in which case the trial shall be done on the sharpest one.

1.2 Initial trial shall be done on the new track with new wheel profile for issue of provisional speed certificate. Repeat trials will subsequently be done on a rundown track as soon as available with worn wheel profile for issue of final speed certificate.

1.3 In case of metros, the long confirmatory run shall be done to obtain at least 25 readings over at least 50 m sections. If not possible in one run, the readings may be obtained by repeatedly running over the same section.

Riding of the vehicle over bridges and viaducts (resonance or amplitude build-up) will be specially mentioned in the trial report.

2.0 MEASURED QUANTITIES

As a part of the Oscillation trials, the following quantities shall be measured:

(i) Body level vertical Accelerations
(ii) Body level lateral Accelerations
(iii) Primary suspension spring deflections

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(iv) Secondary suspension spring deflections
(v) Lateral forces
(vi) Bolster swing, as applicable
(vii) Bogie rotation, as applicable
(viii) Lateral accelerations at bogie frame.
(ix) In case, the section is having a curve sharper than 190m radius, lateral force at rail-wheel contact point shall also be measured with measuring wheel, to be provided by Metro, to calculate the derailment coefficient for issue of final speed certificate.

3.0 CALCULATED QUANTITIES

Ride index shall be calculated as per ORE C-116 (Using FFT). Maximum dynamic wheel loading/unloading ($\Delta Q/Q$) shall also be calculated. Derailment coefficient(Y/Q) over a period of 1/20th second, if required as per Para 2.0, shall also be calculated.

4.0 ROLLING STOCK CONFIGURATION

Usually, trials shall be done in empty and loaded condition initially using new wheel profile. To be repeated with worn wheel profile, as soon as available.

Unless otherwise required by the designer, the free end bogie of Metro coaches will be instrumented. The prototype will thus be the last vehicle in the formation of test special.

5.0 CRITERIA

5.1 Ride index, as per ORE C-116 using FFT method, shall not be greater than 3.00 in inflated and deflated condition in both vertical and lateral directions.
5.2 The values of acceleration recorded, as near as possible to the bogie pivot shall be limited to 0.27g, both in vertical and lateral directions, in inflated and deflated condition.
5.3 A general indication of stable running characteristics of the carriage as evidenced by the movement of the bogie on a straight and curved track, and by the acceleration readings and instantaneous wheel load variations/spring deflections.
5.4 The maximum dynamic wheel loading/unloading ($\Delta Q/Q$) shall not be greater than 0.50.
5.5 *A derailment coefficient, if required as per Para 5.0, should be worked out in the form of ratio between the lateral force (Y) and the instantaneous wheel load (Q) continuously over a period of 1/20th second, the value Y/Q shall not exceed 1, if measured by a measuring wheel.*

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METHODOLOGY FOR EMERGENGY BRAKING DISTANCE TRIALS

Emergency Braking trial is conducted on a new or modified design of rolling stock, which is proposed to be cleared for running on Metro track. The purpose of Emergency Braking trial is, to determine braking characteristics of test train, under load conditions with different modes of operations.

1. Test Train formation and Runs :

The test train shall consist of at least 1 unit/ consist having one prototype representative coach of each type. The trial runs shall be conducted at the maximum speed proposed for operation. The trial is conducted in different loading conditions with dry and wet condition of the rail.

2. Instrumentation:

Unless otherwise required by the design directorate, the free end bogie of the vehicle will be instrumented. The prototype will thus be the last vehicle, of each type, in the formation. The Test Vehicle will be instrumented by testing directorate as per the test scheme, if required by welding suitable plates at the required locations. The following Transducers may be used for the trial:

(1) Pressure Sensors.
(2) Temperature Sensors
(3) Optical Speed Sensors/ Wheel pick up device.
(4) GPS.
(5) Any other transducers required for the trial.

3. Data Acquisition/ Analysis:

Data is acquired by using a Digital data acquisition system, connected to the transducers provided on the prototype vehicle as given in para 2. Sampling rate used is 20 samples /sec. The following parameters are recorded/calculated for evaluation:

STATIONARY TESTS

Following parameters are to be found -

- Initial charging time
- BP charging time after complete draining of AR.
- Brake propagation rate during full service and emergency application
- Brake Application and Release characteristics different application mode.
- Any other test specified by design directorate in trial scheme.

CONDUCTING THE TEST

During stationary test, Continuous pressure records of the following air spaces are made on time basis during stationary tests-

Driving Motor/TC	Brake Pipe (BP) Brake Cylinder (BC) Main Reservoir (MR) Auxiliary Reservoir (AR)
DTC	Brake Pipe (BP) Brake Cylinder (BC) Auxiliary Reservoir (AR)
Driving Motor/TC	Brake Pipe (BP) Brake Cylinder (BC) Auxiliary Reservoir (AR)

The pressure recordings are made with different positions of Driving Cab brake handle order to evaluate various brake characteristics detailed in the test scheme. Before commencement of the stationary test, the following checks / settings are made on the train –

- The brake pipe pressure is at as specified.
- The brake cylinder pressure of the locomotive is set to specified value when brakes are applied through drivers automatic brake handle
- The percentage operative cylinders during stationary test are kept 100%

INITIAL CHARGING OF MAIN RESERVOIR

Before start of the initial charging of main reservoir, the engine is shut down and the air reservoirs are completely drained out by opening the drain cocks. Time taken to charge the MR from zero to maximum pressure is noted with engine running at idle notch.

LEAKAGE RATE

After the pressure in MR and BP is stabilised at the maximum value, the lead /trial switch is turned to lead 'cut-out' position, for putting the pressure maintaining feature of automatic brake out of action to check the leakage in train line brake pipe. Continuous record of MR, BP and FP is taken for 5 minutes to get the leakage rate.

BRAKE APPLICATION

The brake pipe is charged to stabilize for 2 minutes. Using the Master controller handle in the driving Cab, brake is applied and continuous record of various parameters is done. Brake application time for 95% of BC pressure build-up, from the instant of brake application, is worked out to get the brake application time.

BRAKE RELEASE TIME

Release time is defined as the time interval between the driver puts his brake/Master controller handle in release position to the instant the brake cylinder pressure reduces to 0.4 kg/cm^2.

BRAKE APPLICATION FROM LAST VEHICLE AND SIMULATED TRAIN PARTING

The test train is charged for brake pipe pressure of up to designed value and allowed to stabilise for 2 minutes. Brake application is made from the Last Vehicle.. The train parting simulation is done by opening the angle cock from first, middle and rear Vehicle of the train and various parameters are recorded to get an idea of the extent of indication to the driver.

RUNNING TESTS

The following brakes are available on the train

- Emergency brakes (controlled by the Master Controller and the push Button)
- Parking Brake (Controlled by parking brake toggle switch)
- Pneumatic auto Train Brakes (Controlled by a switch)
- Regenerative/Rheostatic Brake and EP Brakes (Controlled by master controller through Electronic control.

Emergency Brake:

Under following emergency conditions data are also recorded

1. Through Anti wheel skid device
2. Through emergency stop push button
3. Through Auto Brake controller

4. Operation of Dead man device
5. Guard's direct emergency brake handle

CONDUCTING THE TEST

For measurement of braking distance, an Optical speed sensor/wheel revolution pick up device is mounted on one axle of the coach for measuring the distance travelled.

The speedometer fitted in the cab is used for guidance in regulating the train speed. The actual speed at the instant of brake application is, however, determined from that recorded by DAQ.

Suitable locations on level track, free from gradient and curve, are pre-selected. Emergency /full service brake application is made, from driver's automatic brake handle from the driving cab, followed by emergency brake application.

Before commencement of running test, the test train is examined and the following is ensured -

- The pressure setting of the brake pipe of the Driving cab is at design value.
- All audible leaks are arrested

4. Facilities to be made available by Metro:

The Metro shall make the following facility available for conducting of trial:

(i) Competent Crew for operating the Test Special.
(ii) Prototype test rake, made suitably fit for trial, for instrumentation and trial runs.
(iii) 220V AC Power supply on board the test special.
(iv) Facility for fixing/mounting for instrumentation, including Welding equipment and manpower, if required.
(v) Fitment of Speed sensor/wheel pick-up device on the vehicle.
(vi) Simulation of wet rail conditions during trial.
(vii) Tapping's for fitment of pressure sensors in the brake system as required.

Any other facility as required by the officer in-charge of the trial for the conduct of the trial.

NOTE: <u>This test procedure is only for general guidance. Nomenclature of various sub-assemblies may be different from those used in this document. Also there may be minor differences in brake systems on different Metros.</u>

Parameters required for calculation of Emergency Braking Distance (EBD), Service Braking Distance (SBD) & controllability of Metro's

1. Type of rolling sock and its composition.
2. Brake rigging diagram including tare & gross weight, brake power, rigging & cylinder efficiency, no. of brake cylinder, maximum brake cylinder pressure (Automatic & Independent) of individual rolling stock.
3. Coefficient of rolling resistance for individual rolling stock (Values of a, b & c in equation $a+bV+cV^2$ (Kg/T) where V is speed in kmph).
4. Type of brake system.
5. Time lag in brake application (Automatic & independent).
6. Emergency & service brake application time of individual rolling stock (Automatic). Also brake development time during independent application.
7. Brake development time in leading, first trailing car & last car in case of emergency and service application.
8. Type of brake rigging (Single shoe, clasp type, TBU or disc brake), brake block & brake block area.
9. Curve of coefficient of friction (Instantaneous & average).
10. Percentage of operative cylinders in train.
11. Speed of operation & amount of maximum down gradient
12. Dynamic brake effort curve for individual power car.
13. Maximum brake cylinder pressure during automatic (Emergency & service) & independent brake application for different type of cars.
14. No. of wheels in individual rolling stock & maximum allowable heat input (Kw) in wheels during controllability.
15. Maximum amount of BP pressure and drop in BP pressure during different stages of automatic brake application & maximum BC pressure corresponding to each stage of application.

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METHODOLOGY FOR COUPLER FORCE TRIALS

Coupler Force trial is conducted on a new or modified design of rolling stock, which is proposed to be cleared for running on Metro track for sections having sustained up gradient steeper than 1 in 100. The purpose of Coupler Force to measure the coupler forces under different operating conditions of a train of newly designed coaches. This test is done to ensure that the coupler forces do not exceed the design limits under actual operating conditions.

The conduct of Coupler Force trial is, generally, guided by the trial scheme given by the Design Directorate.

1. **Test Train formation and Runs** :
   The test train shall consist of at least full train length, which is proposed to be run. The trial runs shall be conducted at the maximum speed proposed for operation. The trial is conducted in loaded conditions.

2. **Instrumentation**:
   Unless otherwise required by the design directorate, the coupler between the 1st and the 2nd vehicle will be instrumented. The prototype will thus be the last vehicle, of each type, in the formation. The following Transducers may be used for the trial:

   (1) Pre-calibrated strain gauged coupler
   (2) Strain gauges
   (3) Optical Speed Sensors/ Wheel pick up device.
   (4) GPS.
   (5) Any other transducers required for the trial.

3. **Data Acquisition/ Analysis**:
   Data is acquired by using a Digital data acquisition system, connected to the transducers provided on the prototype vehicle as given in para 2. Sampling rate used is 20 samples

   A pre-calibrated strain gauged coupler is fitted on the test vehicle between first and second coach and coupler forces and the speeds are recorded under the following operating conditions -

   - Starting of fully released train using maximum tractive effort followed by the alarm chain pulling from last coach after 15 seconds of start
   - Starting of fully released train using maximum tractive effort followed by guard's van valve application after 15 seconds of start
   - Alarm chain pulling from last coach when the train is running at the maximum permissible speed

4. **Facilities to be made available by Metro**:

The Metro shall make the following facility available for conducting of trial:

(i) Competent Crew for operating the Test Special.

(ii) Prototype test rake, made suitably fit for trial, for instrumentation and trial runs.

(iii) 220V AC Power supply on board the test special.

(iv) Facility for fixing/mounting for instrumentation, including Welding equipment and manpower, if required.

(v) Fitment of speed sensor / wheel pick- up device on the vehicle.

(vi) A pre-calibrated strain gauged coupler, along with calibration certificate, as per test requirement.

(vii) Fitment of pre-calibrated strain gauged coupler in the test rake.

(viii) Any other facility as required by the officer in charge of the trial for the conduct of the trial.

NOTE: This test procedure is only for general guidance. Nomenclature of various sub-assemblies may be different from those used in this document. Also, there may be minor differences in brake systems and other features related with coupler force trials on different Metros.

Annexure -I

METHODOLOGY FOR CONTROLLABILITY TRIALS

Controllability Trial is conducted on a new or modified design of rolling stock, which is proposed to be cleared for running on Metro track sections having sustained up gradient steeper than 1 in 100.

The purpose of Controllability Trial is, to determine the controllability of the train on gradient section and temperature increase of the wheel/brake block, under load conditions with different operating conditions.

The conduct of Controllability Trial is, generally, guided by the Test scheme given by the Design Directorate.

1. **Test Train formation and Runs** :

   The test train shall consist of full train length which is proposed to be run. The trial runs shall be conducted starting from the minimum speed up to the maximum speed proposed for operation and on the maximum gradient sections. The trial is conducted in maximum loading conditions with dry and wet condition of the rail.

2. **Instrumentation**:

   The Test Vehicle will be instrumented by Testing Directorate as per the test scheme. The following Transducers may be used for the trial:

   (1) Pressure Sensors.
   (2) Temperature Sensors
   (3) Optical Speed Sensors/ Wheel pick up device.
   (4) GPS.
   (5) Any other transducers required for the trial.

3. **Data Acquisition/ Analysis**:

   Data is acquired by using a Digital data acquisition system, connected to the transducers provided on the prototype vehicle as given in para 2. Sampling rate used is 20 samples. The following parameters are recorded/calculated for evaluation:

STATIONARY TESTS as per Annexure H

RUNNING TESTS

Following are to be determined -

- Braking distance on maximum gradient section on application of emergency brakes.
- Controlling of train with brake application and dynamic brakes within prescribed B.P. drop.
- Wheel/Brake disc and Brake block / brake disc temperature.
- Dynamic current of the driving current.
- Holding of train with Independent driving cab brakes.

CONDUCTING THE TEST

For measurement of braking distance, a Optical speed sensor/wheel revolution pick up device is mounted on one axle of the vehicle for measuring the distance travelled.

The speedometer fitted in the cab is used for guidance in regulating the train speed. The actual speed at the instant of brake application is, however, determined from that recorded by DAQ.

Independent driving cab brakes, are worked in conjunction with train brakes and Suitable locations on maximum gradient track are pre-selected. The brake block and disc temperatures are also recorded along with dynamic current in the driving cab. The wheel temperature and BP pressure drop should be within prescribed limits for safe operation.

The Emergency / full service brake application is made, from driver's automatic brake handle from the driving cab, followed by emergency brake application in conjunction with dynamic brake application. The EBD should be such that train running at maximum permissible speed can be stopped short of signal after sighting the stop signal. On stopping on the maximum gradient section, the holding test of the train with independent driving cab brakes, with train brakes in released position, shall be carried out. A number of such readings are taken, depending on the section length.

Before commencement of running test, the test train is examined and the following is ensured -

- The pressure setting of the brake pipe of the driving unit is at specified value.
- All audible leaks are arrested.

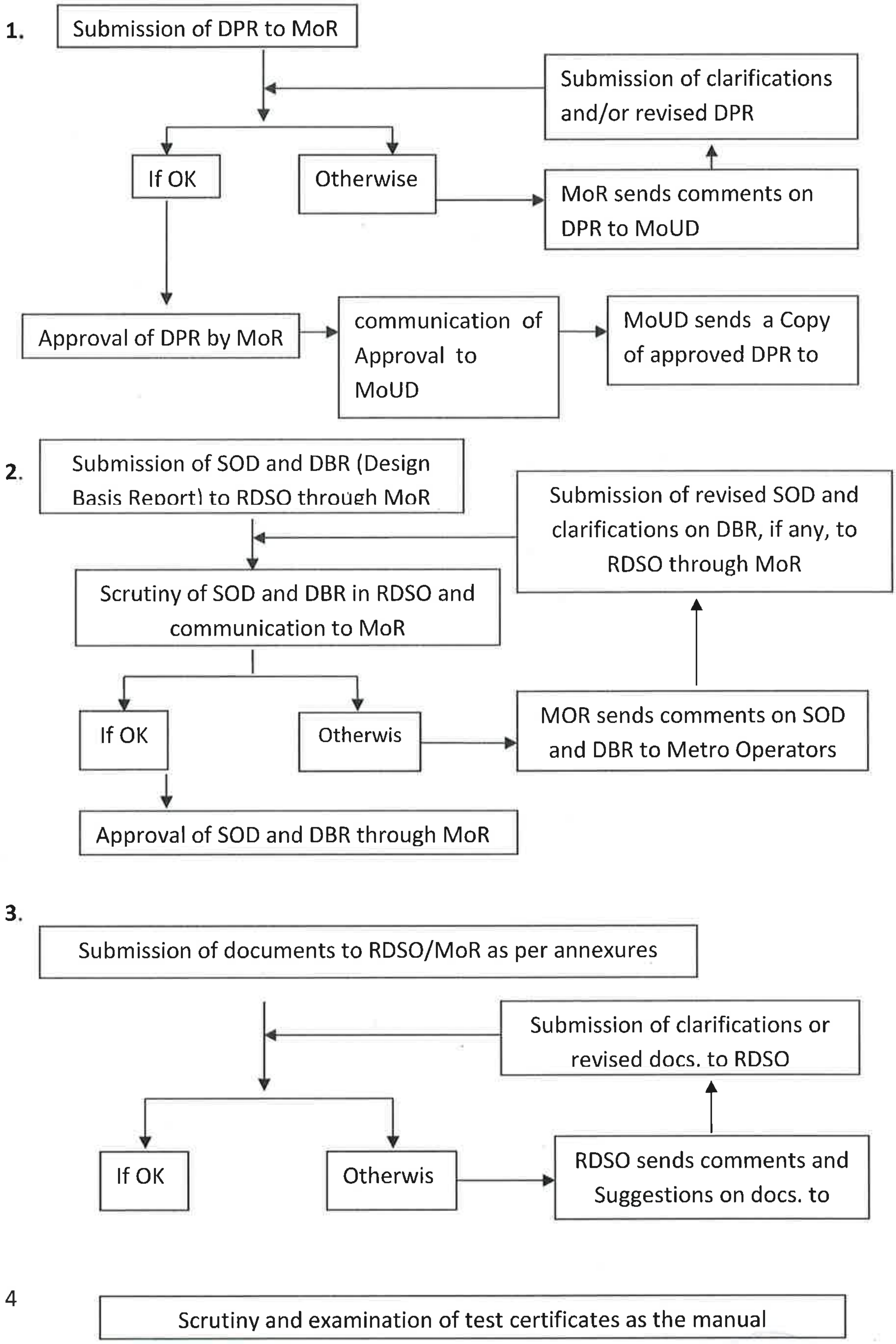
4. **Facilities to be made available by Metro**:

The Metro shall make the following facility available for conducting of trial:

i. Competent Crew for operating the Test Special.
ii. Prototype test rake, made suitably fit for trial, for instrumentation and trial runs.
iii. 220V AC Power supply on board the test special.
iv. Fitment of Speed sensor/wheel pick-up device on the vehicle.
v. Simulation of wet rail conditions during trial.
vi. Tapping's for fitment of pressure sensors in the brake system as required.
vii. Any other facility as required by the officer in charge of the trial for the conduct of the trial.

NOTE: This test procedure is only for general guidance. Nomenclature of various sub-assemblies may be different from those used in this document. Also there may be minor differences in brake systems on different Metros.

FLOW CHART FOR METRO CERTIFICATION PROCEDURE



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5 Issue of speed certificate by RDSO for conducting speed Trial

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If Metro line already opened for Public Carriage of Passengers

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Metro applies to CRS /CMRS for sanction for conducting oscillation trial

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Sanction of CRS /CMRS for conducting oscillation trial

If Metro line yet to be opened for Public Carriage of

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6. RDSO conducts oscillation & EBD trials

↓

RDSO conducts coupler force, controllability and/or any other special test, if required

↓

RDSO issues interim speed certificate for regular use of rolling stock

↓

Metro applies for sanction of Rolling Stock to MoR through CRS

↓

Sanction of MoR /Railway Board of Rolling stock

↓

Action to be taken by the Metro Administration for Opening of Metro, as per "Opening of Metro Railway for Public Carriage of Passenger Rules, 2013" with latest amendment.

दिल्ली मेट्रो रेल कारपोरेशन लि. Delhi Metro Rail Corporation Ltd. N.B.C.C. Place एन.बी.सी.सी. प्लेस

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Guidelines for Noise & Vibrations

DESIGN, MANUFACTURE, SUPPLY, TESTING, COMMISSIONING AND TRAINING OF 378 NOS. OF STANDARD GAUGE METRO RAIL CARS FOR MUMBAI METRO RAIL INVESTMENT PROJECT

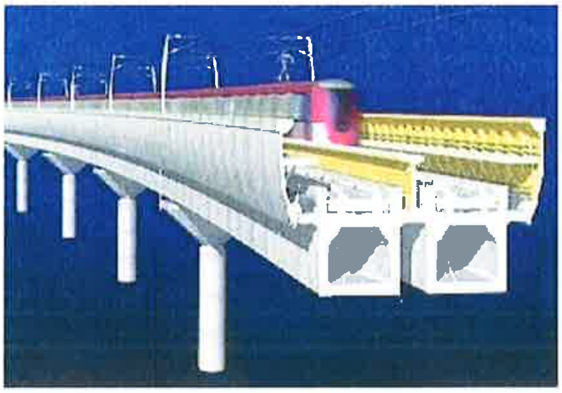
CONTRACT AGREEMENT
CONTRACT 'MRS1'

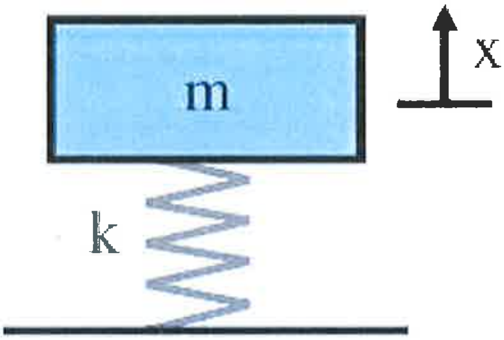
PART-I

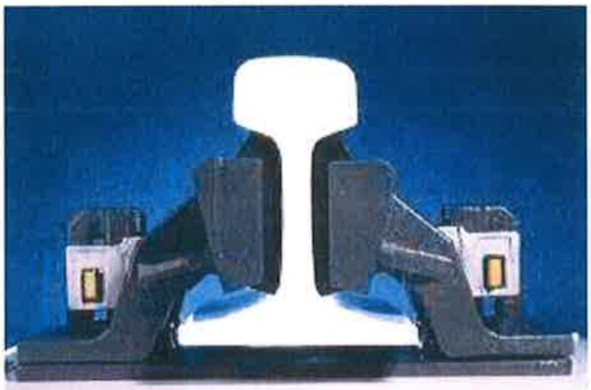
GUIDELINES FOR NOISE AND VIBRATIONS

Metro Rail Transit System

Guidelines
for
Noise and Vibrations







September, 2015

CT- 38
Track Design Directorate
Research Designs and Standards Organisation
Ministry of Railways, India

000660

Preamble

The noise and vibration from Mass Transit Systems can adversely impact environment during construction and operation. Government of India has approved number of metro corridors in many densely populated cities. The future will see more such projects. This would need a frame work of environmental aspects to be taken care of while going for such new developments as well as addressing related problems for existing metro corridors, if any. Since the construction period remains limited, the metro rail systems shall take necessary precautionary measures against environmental impact during construction in consultation with the State Government. This document lays guidelines for noise reference levels, vibration impact criteria for detailed analysis, noise and vibration mitigation measures, and ways of reducing excessive noise and vibration caused by metro railway projects, *hereafter referred as* rail transit systems/projects. In view of the importance of the subject, on the request of Delhi Metro, Ministry of Railways formed a committee to go through the subject comprehensively and recommend necessary guidelines. The committee consists of:

(i) Executive Director/Works (Planning), Rly. Board, Shri K K Aggarwal (convener)

(ii) Executive Director/Track-II, Research Designs & Standards Organisation (RDSO), Shri Vipul Kumar

(iii) Chief General Manager/Track, DMRC, Shri A K Singhal

(iv) Sh Mukesh Dwivedi, Track Expert with M/s L&T and M/s Alstom JV recommended by Chennai metro

Shri S. P. Iyer, track expert, General Consultant recommended by Bangalore metro was also associated with the committee and has contributed in framing the recommendations.

The committee has gone comprehensively in the subject of metro rail transit generated noise and vibrations and has made an attempt to create a document on the subject. The aim has been to produce a document that provides details of basics of noise and vibrations (N&V) for the benefit of engineers dealing with the subject as the subject is new and complex for metro rail transit authorities in India. The document provides guidelines for threshold values of N&V; carrying out impact assessment study both at the design and operation stages; taking required mitigation measures; etc.

In India, railway locomotives are exempted from the provisions of "The Noise Pollution (Regulation and Control) Rules 2000. These rules are also silent regarding the limits for ground borne vibrations and noise. As such no other document is available in India, as the best known to the committee members, which deals with the subject in required detail for rail transit domain.

Therefore, the subject of Noise and Vibrations discussed in this document is based on information available in standards in India and study of similar standards from USA, Europe and Australia, which are in turn based on intensive surveys of human and industrial habitations, knowledge provided by health authorities such as the National Health and Medical Research Council of these countries, the World Health Organization (WHO), etc. While going into the details of the subject, the committee learnt through the interactions with technical personnel dealing with the subject on advance railway systems in Europe that the subject has been dealt comprehensively by Planning and Environment Department, Federal Transport Authority (FTA), USA. Though the committee while drafting this document has gone through many documents issued in Europe e.g. ISO-14837-1, Australia e.g. 'Guidelines for the Assessment of Noise from Rail Infrastructure' issued by Environment Protection Authority, South Australia, etc., the content of this document is primarily based on 'Transit Noise and Vibration Impact Assessment' of May, 2006 issued by Office of Planning and Environment, FTA, USA (FTA Manual) for it being one of the most comprehensive, informative and practiced documents on the subject. The readers who may desire to refer to the original document for more detailed study may obtain it from www.fta.dot.gov. (FTA-VA-90-1003-06)

The draft guidelines were circulated to the stakeholders for comments with uploading on RDSO website on May 21, 2015. The comments which were received from stakeholders were examined by RDSO and incorporated wherever found relevant. The revised draft guidelines were again uploaded on RDSO web site on Aug. 7, 2015 for information of the stakeholders. The document now being circulated as Guidelines, after incorporating comments from stakeholders, has the approval of Ministry of Railways, the nodal ministry for technical planning and safety of metro rail systems in India. The document is available on the website of Track Design Directorate as well as Urban Transport & High Speed Directorate of RDSO.

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Introduction

I.1 The following may be the impact on environment from operation of metro rail services.

i) Air-borne noise (Radiated noise)
ii) Ground-borne vibration in neighbouring buildings
iii) Ground borne noise in neighbouring buildings
iv) Air-borne noise inside trains.

The aspect of air-borne (radiated) noise inside train is generally covered by train set designers, only first three types of noise and vibrations are covered in this document.

I.2 Noise and Vibration Analysis for a Project

Generally, metropolitan rail transit project planning process includes the consideration of social, economic, and environmental effects. However, at the initial stages, environmental effects are usually considered on a broad scale, for example, overall development patterns, impact on green space/forests, etc. Noise and vibration impact assessments are not typically done at the systems planning stage since the proposed infrastructure improvements lack the necessary detail.

Once the need for a major capital investment in a corridor is established, the task of identifying the transit mode and alignment best suited for the corridor is undertaken. Usually, several alternatives ranging in cost are evaluated. If environmental impacts of the alternatives are assessed, noise and, to a lesser extent, vibration needs to be considered as primary issues. The screening and general assessment should be carried out to compare noise/vibration impact among different modes and alignments.

If the results of the alternatives analysis justify going for a given alternative in terms of transit mode or alignment, preliminary engineering or Detailed Project Study (DPS) is undertaken. During preliminary engineering/DPS, the environmental review process is completed. With the mode and alignment determined, the impact assessment at this stage focuses on the locally preferred alternative. The detailed analysis procedures for noise can be used to produce the most accurate estimates of noise impact for the proposed project. The detailed procedures should be used as the basis for reaching any decisions on the need for noise reduction measures and the types of measures that are appropriate for the project.

If vibration impacts were identified during preliminary engineering/DPS stage, a detailed analysis of vibration impact should be conducted during final design. Final design activities will produce the geotechnical information needed to define the impact assessment and allow the most detailed consideration of vibration control measures, if needed. Even for smaller transit projects, if vibration impact is predicted in a general assessment, vibration mitigation measures should only be specified after a detailed analysis has been done. Detailed vibration analysis is best accomplished during final design of the project.

Once the project enters construction stage, there may still be a need for noise or vibration analysis in some circumstances. Large construction projects in densely populated residential areas may require noise monitoring to make sure that agreed-upon noise limits are not exceeded. Vibration testing may be needed in the final stages of construction to determine whether vibration control measures are having the predicted effect.

Considering that transit projects must be located amid or very close to concentrations of people, noise and vibration impacts can be a concern throughout the planning and project development phases. There are three levels of analysis which may be employed, depending on the type and scale of the project, the stage of project development, and the environmental setting. The summary of each level is given in the following paragraphs:

- **Screening Procedure:** Identifies noise and vibration sensitive land uses in the vicinity of a project and whether there is likely to be an impact. It also serves to determine the noise and vibration study areas for further analysis when sensitive locations are present. The screening process may be all that is required for many of the smaller transit projects which qualify as categorical exclusions. When noise/vibration- sensitive receivers are found to be present, there are two levels of quantitative analysis available to predict impact and assess the need for mitigation measures.

- **General Assessment:** Identifies location and estimated severity of noise and vibration impacts in the noise and vibration study areas identified in the screening procedure. For major capital investments, the General Assessment provides the appropriate level of detail to compare alternative modes and alignments in alternatives analysis. It can be used in conjunction with established highway noise prediction procedures to compare and contrast highway, transit and multimodal alternatives. Before basic decisions have been reached on mode and alignment in a corridor, it is not prudent to conduct the most detailed level of noise and vibration analysis. For smaller transit projects, this level is used for a closer examination of projects which shows possible impacts as a result of screening. For many smaller projects, this level may be sufficient to define impacts and determine whether mitigation is necessary.

- **Detailed Analysis:** Quantifies impacts through an in-depth analysis usually only performed for a single alternative. Delineates site-specific impacts and mitigation measures for the preferred alternative in major investment projects during preliminary engineering. For other smaller projects, Detailed Analysis may be warranted as part of the initial environmental assessment if there are potentially severe impacts due to close proximity of sensitive land uses.

I.3 Normally the vibration should not affect the buildings designed to standards and kept in reasonable state of maintenance, as the vibration magnitudes are small compared to those from earth quakes. However, vibration inside the buildings can affect the people and sensitive equipment such as in hospitals, broadcasting stations, religious institutions etc. Vibrations can also affect heritage structures. The standards laid down are meant to protect these structures and activities inside from train noise and vibrations.

I.4 Based on the study carried out, the metro railway administrations (MRA) shall, once the project is approved, notify to the public that all structures taken up for construction after the date of such notification, shall be designed to safe guard against noise and vibration from the Metro system as and when commissioned, and that Metro Rail Transit system will not be responsible for any environmental impact to those buildings arising out of metro rail operations subsequent to date of notification.

I.5 This document is organized in the following topics.

- Introduction
- Noise - Basic Concepts.
- Basics of Ground-borne noise and vibration
- Noise and Vibrations Impact Criteria (Recommended Norms/Threshold Values for metro corridor in India for Noise and Vibrations).
- Vibration Screening Procedures.
- Detailed vibration analysis.
- Noise and vibration Mitigation

Chapter-1

Noise - Basic Concepts

1.1 The Sound is what humans hear when exposed to pressure fluctuations in air. Noise is unwanted sound. Sound can be described in terms of amplitude (loudness), frequency (pitch) and time pattern (variability).

Source-Path-Receiver framework indicated in Figure 1.1 is basic to all environmental noise studies. Each transit **source** generates close-by noise levels which depend upon the type of source and its operating characteristics. Then, along the propagation **path** between all sources and receivers, noise levels are reduced (attenuated) by distance, intervening obstacles and other factors. And finally at each **receiver**, noise combines from all sources to interfere, perhaps, with receiver activities.

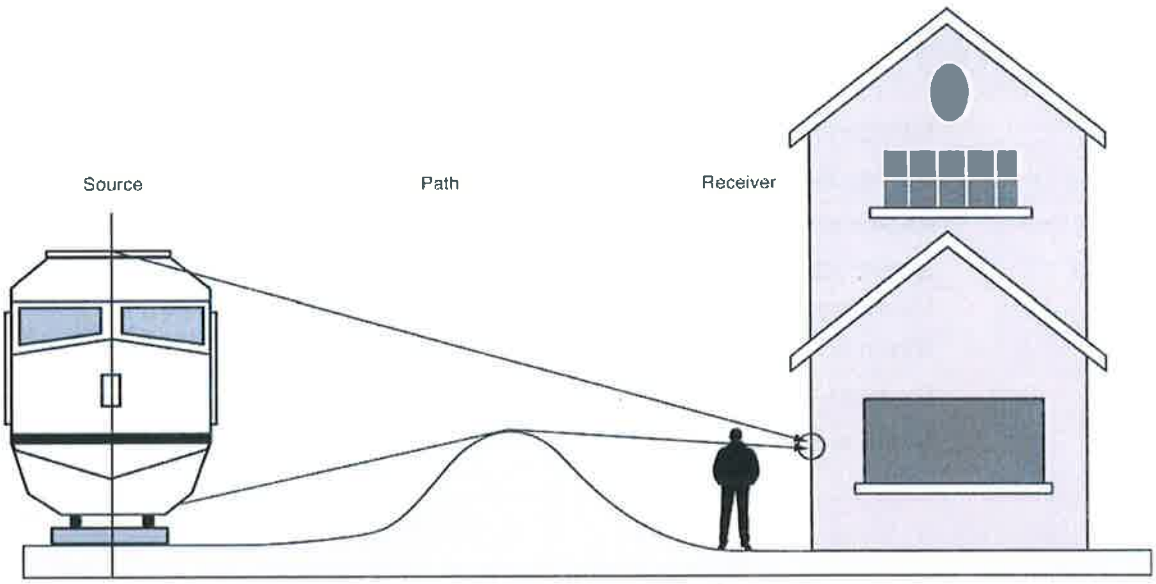


Figure 1.1. The Source-Path-Receiver Framework

1.2 FUNDAMENTALS OF NOISE

1.2.1 Amplitude.

Sound wave makes fluctuations in atmospheric pressure. The amplitude of fluctuation is related to the energy carried in a sound wave. The greater the amplitude, the greater the energy and the louder is the sound. The magnitude of sound pressure in a sound wave is expressed by the root mean square value of the oscillating pressure in Pascals

The 'threshold' of human hearing is a sound pressure of about 20 micro pascals. The loudest sound is a sound pressure of 20 million micro pascals. For convenience, sound pressure is defined in decibels (dB).

Sound pressure level $L_p = 10 \log_{10} (p^2_{rms} / p^2_{ref}) = 20 \log_{10} (p_{rms} / p_{ref})$ dB, Where p_{ref} =20 micro Pascals = 2×10^{-5} N/m^2 =0 .0002dyn/cm^2 = 0 dB.

Therefore, Loudest sound of 20 million microPascals is 120 dB

Thus the audible range is 0 dB to 120 dB.

1.2.2 Average noise level at a location

If the noise levels at a particular location are L_1 ,L_2, L_3 in bels (10 dB =1B) measured during an hour of the day, the average noise level at the location is arrived at by logarithmetic averaging.

$$L = 10 \times \log_{10} [(10^{L1} + 10^{L2} + 10^{L3})]/3$$

This also indicates that doubling of identical sound sources results in 3 dB increase, since:

$$10 \log_{10} (2p^2_{rms} / p^2_{ref}) = 10 \log_{10} (p^2_{rms} / p^2_{ref}) + 10 \log_{10} (2) = 10 \log_{10} (p^2_{rms} / p^2_{ref}) + 3$$

1.2.3 Frequency

Sound is a fluctuation of air pressure. The number of times the fluctuation occurs in one second is called its frequency and frequency is quantified in cycles per second, or Hertz (abbreviated Hz). Some sounds, like whistles, are associated with a single frequency; this type of sound is called a "pure tone." Most often, however, noise is made up of many frequencies, all blended together in a spectrum. Human hearing covers the frequency range of 20 Hz to 20,000 Hz. If the spectrum is dominated by many low frequency components, the noise will have a characteristic like the rumble of thunder.

The spectrum in Figure 1.2 illustrates the full range of acoustical frequencies that can occur near a transit system. In this example, the noise spectrum was measured near a train on a steel elevated structure with a sharp curve. This spectrum has a major low frequency peak centered around 80 Hz. Although not dominant in this example, frequencies in the range of 500 Hz to 2000 Hz are associated with the roar of wheel/ rail noise. However a strong peak above 2000 Hz is associated with the wheel squeal of the train on the curve.

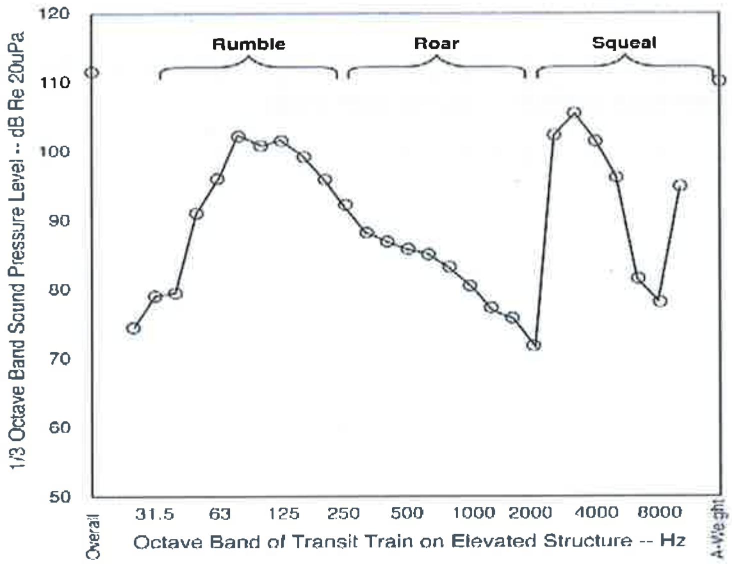


Figure 1.2. Noise Spectrum of Transit Train on Curve on Elevated Structure

Human hearing system does not respond equally to all frequencies of sound. For sounds normally heard in our environment, low frequencies below 250 Hz and very high frequencies above 10,000 Hz are less audible than the frequencies in between. Acoustical scientists measured and developed frequency response functions that characterize the way people respond to different frequencies. These are the so-called A-, B- and C-weighted curves, representing the way people respond to sounds of normal, very loud and extremely loud sounds, respectively. Environmental noise generally falls into the "normal" category so that the A- weighted sound level is considered best to represent the human response.

1.2.4 Time pattern

The third important property of noise is its variation in time. Environmental noise generally consists of a conglomeration of noise from distant sources. Such sources may include distant vehicular traffic, wind in obstructions, and distant industrial or construction activities, all part of our daily lives. These distant sources create a low-level "background noise" in which no particular individual source is normally identifiable. Background noise is often relatively constant from moment to moment, but varies gradually from hour to hour as natural forces as well as human activities may change. Superimposed on this low-level, gradually varying background noise is a succession of identifiable noisy events of relatively brief duration. These events may include single-vehicle passage, aircraft flyovers, screeching of brakes, and other short-term events, all causing the noise level to fluctuate significantly from moment to moment.

It is possible to describe these fluctuating noises in the environment using single-number descriptors. The search for adequate single- number noise descriptors has encompassed hundreds of attitudinal surveys and laboratory experiments, plus decades of practical experience with many alternative descriptors done in USA and other advance railway systems.

1.3 SOURCES OF TRANSIT NOISE

Transit noise is generated by transit vehicles in motion. Vehicle propulsion units may generate following type of noise:

i) Whine from electric control systems and traction motors that propel rapid transit cars
ii) Diesel-engine exhaust noise, from both diesel-electric locomotives and transit buses
iii) Air-turbulence noise generated by cooling fans
iv) Gear noise

Additional noise of motion is generated by the interaction of wheels/tires with their running surfaces. The interaction of steel wheels and rails generates three types of noise:

i) Rolling noise due to continuous rolling contact
ii) Impact noise when a wheel encounters a discontinuity in the running surface, such as a rail joint, turnout or crossover
iii) Squeal generated by friction on tight curves.

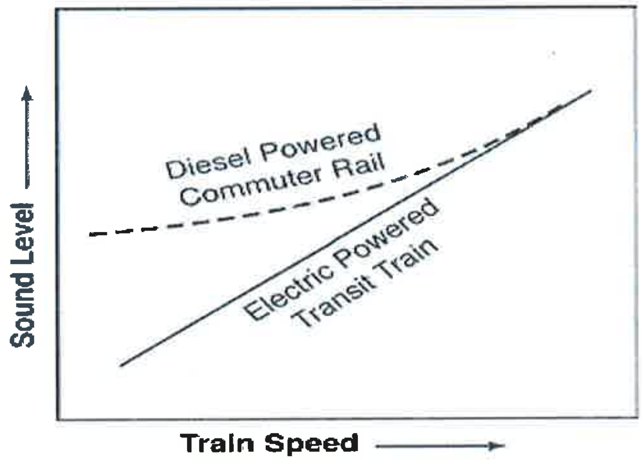


Figure 1.3. Example Sound Level Dependence on Speed

Fig. 1.3 illustrates typical dependence of source strength on vehicle speed for two types of traction vehicles. In this figure, vertical axis indicates the maximum sound level during a passby vis-à-vis train speed on the abscissa. As can be seen, the speed dependence is strong for electric-powered transit trains because wheel/rail noise dominates, and noise from this source increases strongly with increasing speed. On the other hand, speed dependence is less for diesel-powered trains, particularly at low speeds where the noise from the locomotive dominates. As speed increases, wheel-rail noise becomes the dominant noise source and diesel- and electric-powered trains will generate similar noise levels. For transit vehicles in motion, close-by sound levels also depend upon other parameters, such as vehicle acceleration and vehicle length, plus the type/condition of the running surfaces. For very high-speed rail vehicles, air turbulence can also be a significant source of noise. In addition, the rail/track structure can also radiate noise as it vibrates in response to the dynamic loading of the moving vehicle.

Noise is generated by transit vehicles even when they are stationary. For example, auxiliary equipment often continues to run even when vehicles are stationary – equipment such as cooling fans on motors, radiator fans, plus hydraulic, pneumatic and air-conditioning pumps. Noise is also generated by sources at fixed-transit facilities. Such sources include ventilation fans in transit stations, in subway tunnels, and in power substations, equipment in chiller plants, and many activities within maintenance facilities and shops.

1.4 PATHS OF TRANSIT NOISE

Sound travels from source to receiver predominantly through the air. Along these paths, sound reduces with distance due to (a) divergence, (b) absorption/diffusion and (c) shielding. These mechanisms of sound attenuation are discussed below.

Divergence: Sound levels naturally attenuate due to distance with longer path of travel leading to increased attenuation. This is called "divergence," and depends upon source configuration and source-emission characteristics. For sources grouped closely together (called point sources), attenuation with distance is large, being almost 6 decibels per doubling of distance. Point sources include crossing signals along rail corridors, PA systems in maintenance yards and other closely grouped sources of noise. On the other hand, for vehicles passing along a track or roadway (called line sources), divergence with distance is less, being around 3 decibels per doubling of distance.

Absorption/Diffusion: In addition to distance alone, sound levels are further attenuated when sound paths lie close to freshly-plowed or vegetation-covered ground and can be as large as 5 decibels for few hundred meters. At very large distances, wind and temperature gradients sometimes modify the ground attenuation discussion of which is not included in this document as they generally occur beyond the range of typical transit-noise impact.

Shielding: Sound paths are sometimes interrupted by natural or man-made noise barriers e.g. by terrain, by rows of buildings, or by vegetation. Most important of these path interruptions are noise barriers, also considered one of the best means of mitigating noise in sensitive areas. A noise barrier reduces sound levels at a receiver by breaking the direct line-of-sight between source and receiver with a solid wall (in contrast to vegetation, which hides the source but does not reduce sound levels significantly). Sound energy reaches the receiver in reduced proportion only by bending or through the process of diffraction over the top of the barrier as indicated in figure 1.4 as follows:

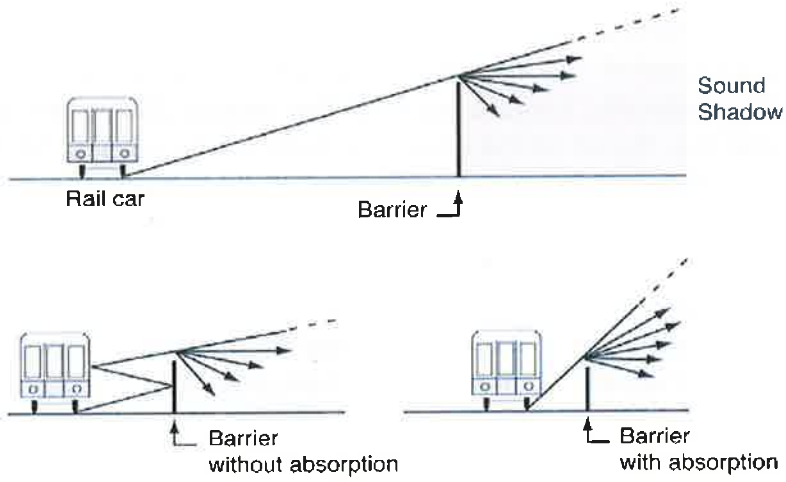


Fig. 1.4, Noise Barrier Mechanism

Use of sound barriers for controlling radiated or air-borne transit noise is typically made to attenuate noise at the receiver by 5 to 15 decibels, depending upon barrier height, length, and distance from both source and receiver. Barriers on structure, very close-in to the source, sometimes provide less attenuation than do barriers slightly more distant from the source, due to reverberation (multiple reflections) between the barrier and the body of the vehicle. However, this reverberation is often offset by increased barrier height, which is easy to obtain for such close- in barriers, and/or acoustical absorption on the source side of the barrier.

Sometimes a portion of the source-to-receiver path is not through the air, but rather through the ground or through structural components of the receiver's building. Discussion of such ground-borne and structure-borne propagation is done in subsequent sections of this document.

1.5 RECEIVER RESPONSE TO TRANSIT NOISE

Noise can be severe enough to interrupt ongoing activities and can result in community annoyance, especially in residential areas. In general, most residents become highly annoyed when noise interferes significantly with activities such as sleeping, talking, noise-sensitive work, and watching TV or listening to music. In addition, some land uses, such as outdoor concert pavilions, theaters, etc. are inherently sensitive to high noise levels.

Annoyance to noise has been investigated and approximate dose-response relationships have been quantified by the Environmental Protection Agency (EPA) of United States of America. The selection of noise descriptors in this manual is largely based upon this EPA work. Beginning in the 1970s, the EPA undertook a number of research and synthesis studies relating to community noise of all types. Results of these studies have been widely published, and discussed and refereed by many professionals in acoustics. Basic conclusions of these studies have been adopted by the Federal Interagency Committee on Noise, the Department of Housing and Urban Development (HUD), the American National Standards Institute and even internationally. Conclusions from this seminal EPA work remain scientifically valid to this day. Based on the extensive study, it was inferred that community reaction varies from "No Reaction" to "Vigorous Action," for newly introduced noises averaging from "10 decibels below existing" to "25 decibels above existing."

Through a large number of community attitudinal surveys done in US, it was found that the percentage of high annoyance is approximately 0 percent at 45 decibels, 10 percent around 60 decibels and increases quite rapidly to approximately 70 percent around 85 decibels.

As inferred through studies, the introduction of transit noise into a community may have two undesirable effects. First, it may significantly increase existing noise levels in the community, levels to which residents have mostly become accustomed. This effect is called "relative" noise impact. Evaluation of this effect is "relative" to existing noise levels; relative criteria are based upon noise increases above existing levels. Second, newly introduced transit noise may interfere with community activities, independent of existing noise levels; it may be simply too loud to converse or to sleep. This effect is called "absolute" noise impact, because it is expressed as a fixed level not to be exceeded and is independent of existing noise levels.

1.6 DESCRIPTIORS FOR TRANSIT NOISE

1.6.1 A-Weighted Sound Level: Basic Noise Unit

To represent the way people respond to normal, very low and very high frequencies, frequency response functions are developed, called A, B and C weighted curves. Environmental noise generally falls in the 'normal' category for which the A-weighted decibel (dBA) is considered best to represent the human response. During measurement it is read directly from noise-monitoring equipment, with the "weighting switch" set on "A." Figure 1.5 shows some typical A-weighted Sound Levels for both transit and non-transit sources.

As is apparent from Figure 1.5, typical A-weighted Sound Levels range from the 40 dBA to 90 dBA, where 30 is very quiet and 90 is very loud. It is important to note that without this A-weighting, noise-monitoring equipment would respond to events people cannot hear, events such as high- frequency dog whistles and low-frequency seismic disturbances. On the average, each A-weighted sound level increase of 10 decibels corresponds to an approximate doubling of subjective loudness. Other frequency weighting such as B, C, and linear weights have been used to filter sound for specific applications and are not discussed in this document.

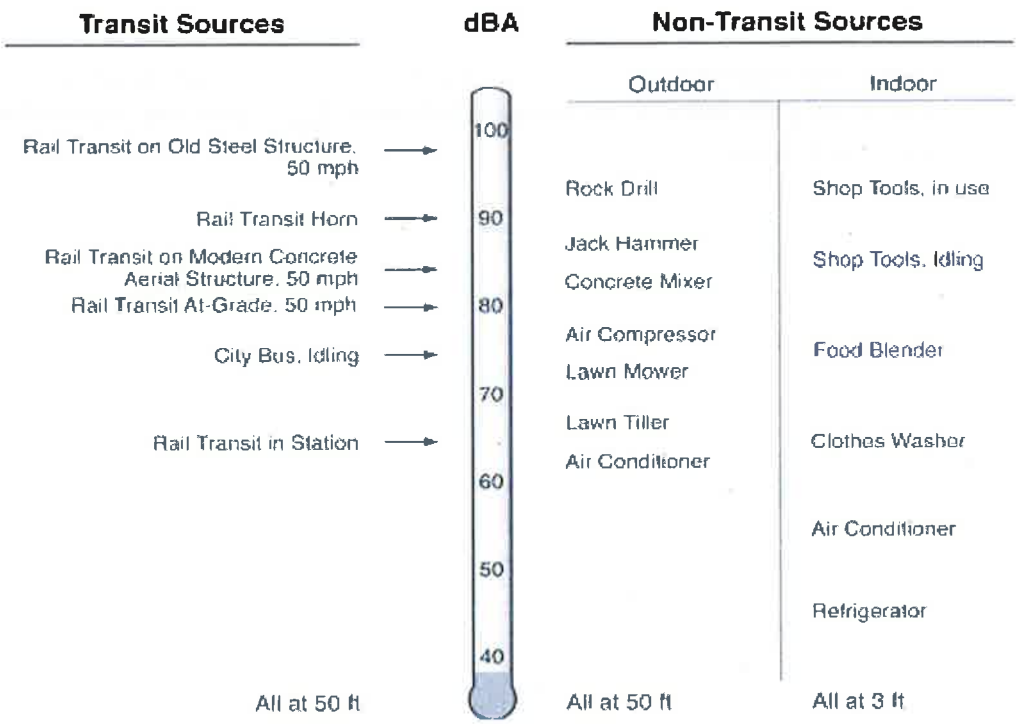


Figure 1.5, Typical A-weighted Sound Levels measured at 15.2m (50 ft) and 0.91m (3 ft)

A-weighted sound levels are adopted as the basic noise unit because: (1) they can be easily measured, (2) they approximate human ear's sensitivity to sounds of different frequencies, (3) they match attitudinal-survey tests of annoyance better than do other basic units, (4) they have been in use since the early 1930s, and (5) they are endorsed as the proper basic unit for environmental noise by nearly every agency concerned with community noise throughout the world.

1.6.2 Maximum Sound Level (L_{max}) during a Single Noise Event

As a transit vehicle approaches, passes by, and then recedes into the distance, the A-weighted sound level rises, reaches a maximum, and then fades into the background noise. The maximum A-weighted sound level reached during this passby is called the Maximum Sound Level, abbreviated here as "L_{max}." For noise compliance tests of transient sources, such as moving transit vehicles under controlled conditions with smooth wheel and rail conditions, L_{max} is typically measured with the sound level meter's switch set on "fast." However, for tests of continuous or stationary transit sources, and for the general assessment of transit noise impact, it is usually more appropriate to use the "slow" setting. When set on "slow," sound level meters ignore some of the very transient fluctuations, which are unimportant to people's overall assessment of the noise. L_{max} is illustrated in Figure 1.6, where time is plotted horizontally and A-weighted sound level is plotted vertically

Because L_{max} is commonly used in vehicle-noise specifications and because it is commonly measured for individual vehicles, equations are included in Appendices E and F of FTA Manual to convert between L_{max} and the cumulative descriptors discussed below.

However, L_{max} is not used as the descriptor for transit environmental noise impact assessment for several reasons. Lmax ignores the number and duration of transit events, which are important to people's reaction to noise, and cannot be totaled into a one-hour or a 24-hour cumulative measure of impact. Moreover, the L_{max} is not conducive to comparison among different transportation modes. For example, noise descriptors used in highway noise assessments are L_{eq} and L_{10}, the noise level exceeded for 10 percent of the peak hour.

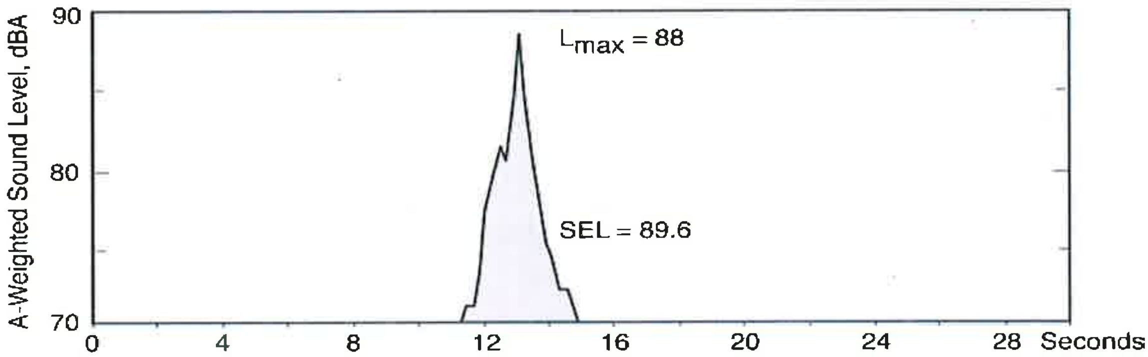


Fig. 1.6. Typical Transit Vehicle Pass-by

1.6.3 Sound Exposure Level (SEL): Cumulative Exposure from a Single Noise Event

Shaded portion in Figure 1.6 indicates the noise "exposure" during a transit-vehicle passby. This exposure represents the total amount of sound energy that enters the receiver's ears (or the measurement microphone) during the vehicle passby. Figure 1.7 shows another noise event – this one within a fixed-transit facility as a transit car/locomotive is started, warmed up, and then driven away. For this event, the noise exposure is large due to duration. The quantitative measure of the noise exposure for single noise events is the Sound Exposure Level, abbreviated here as "SEL" and shaded in both these figures. The fact that SEL is a cumulative measure means that (1) louder events have greater SELs than do quieter ones, and (2) events that last longer in time have greater SELs than do shorter ones.

People react to the duration of noise events, judging longer events to be more annoying than shorter ones, assuming equal maximum A-Levels. Mathematically, the Sound Exposure Level is computed as:

$$SEL = 10 \log_{10} [\text{Total Sound Energy during the Event}]$$

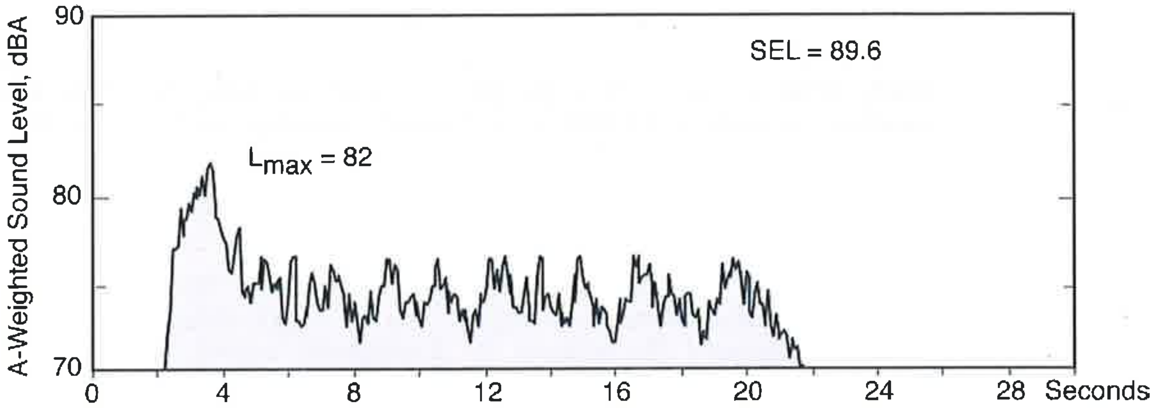


Fig. 1.7, Typical Fixed Facility Noise Event

Fig. 1.8 repeats the previous time histories, but with a stretched vertical scale. The stretched scale corresponds to sound "energy" at any moment in time. Note that the shaded zones in the two frames have equal numerical areas, corresponding to equal SELs for these two very different noise events

Each frame of the figure also contains a tall, thin shaded zone of one-second duration. This tall zone is another way to envision SELs. Think of the original shaded zone being squeezed shorter and shorter in time, while retaining the same numerical area. As its duration is squeezed, its height must increase to keep the area constant. If an SEL shading is squeezed to a duration of one second, its height will then equal its SEL value. Note that the resulting height of the squeezed zone depends both upon the Lmax and the duration of the event -- that is, upon the total area under the original, time- varying A-Level. Often this type of "squeezing" helps communicate the meaning of SELs and noise doses to the reader.

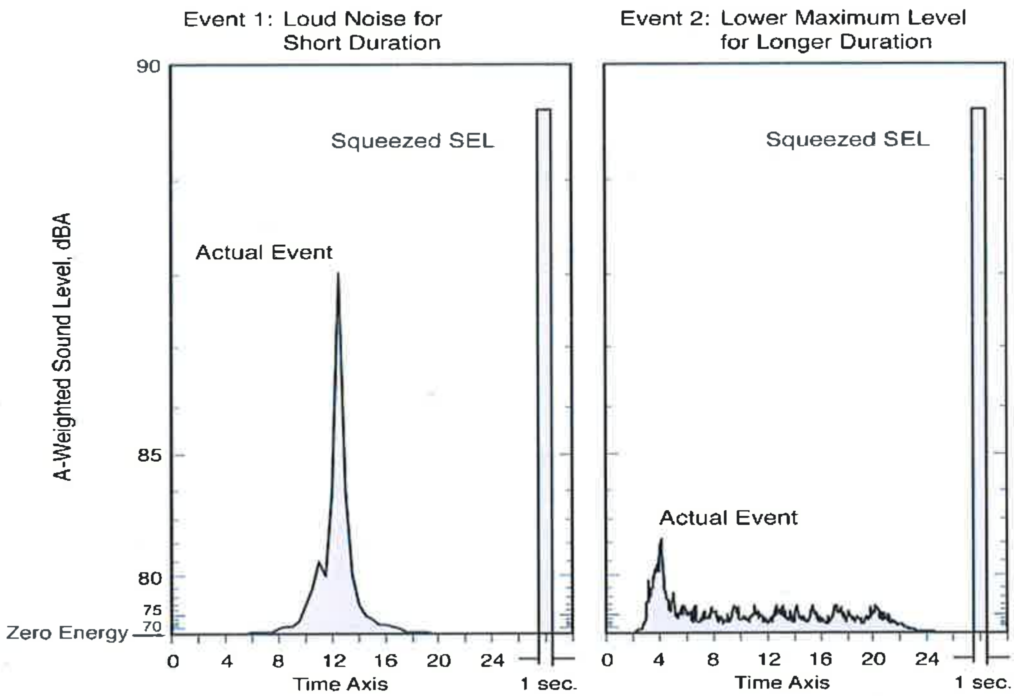


Fig. 1.8, An Energy View of Noise Events

SEL is used in this document as the cumulative measure of each single transit-noise event because unlike L_{max}, (1) SEL increases with the duration of a noise event, which is important to people's reaction, (2) SEL, therefore, allows a uniform assessment method for both transit-vehicle passbys and fixed-facility noise events, and (3) SEL can be used to calculate the one-hour and 24-hour cumulative descriptors discussed below.

1.6.4 **Hourly Equivalent Sound Level - Leq(h)**

The descriptor for cumulative one-hour exposure is the Hourly Equivalent Sound Level, abbreviated here as "Leq(h)." It is an hourly measure that accounts for the moment-to-moment fluctuations in A-weighted sound levels due to all sound sources during that hour, combined. Sound fluctuation is illustrated in the upper frame of Figure 1.9 for a single noise event such as a train passing on nearby tracks. As the train approaches, passes by, and then recedes into the distance, the A-weighted Sound Level rises, reaches a maximum, and then fades into the background noise. The area under the curve in this upper frame is the receiver's noise dose over this five-minute period.

The center frame of the figure shows sound level fluctuations over the one-hour period that includes the five- minute period from the upper frame. Now the area under the curve represents the noise exposure for one hour. Mathematically, the Hourly Equivalent Sound Level is computed as:

$$L_{eq}(\text{hour}) = 10 \log_{10} [\text{Total Sound Energy during one hour}] - 35.6$$

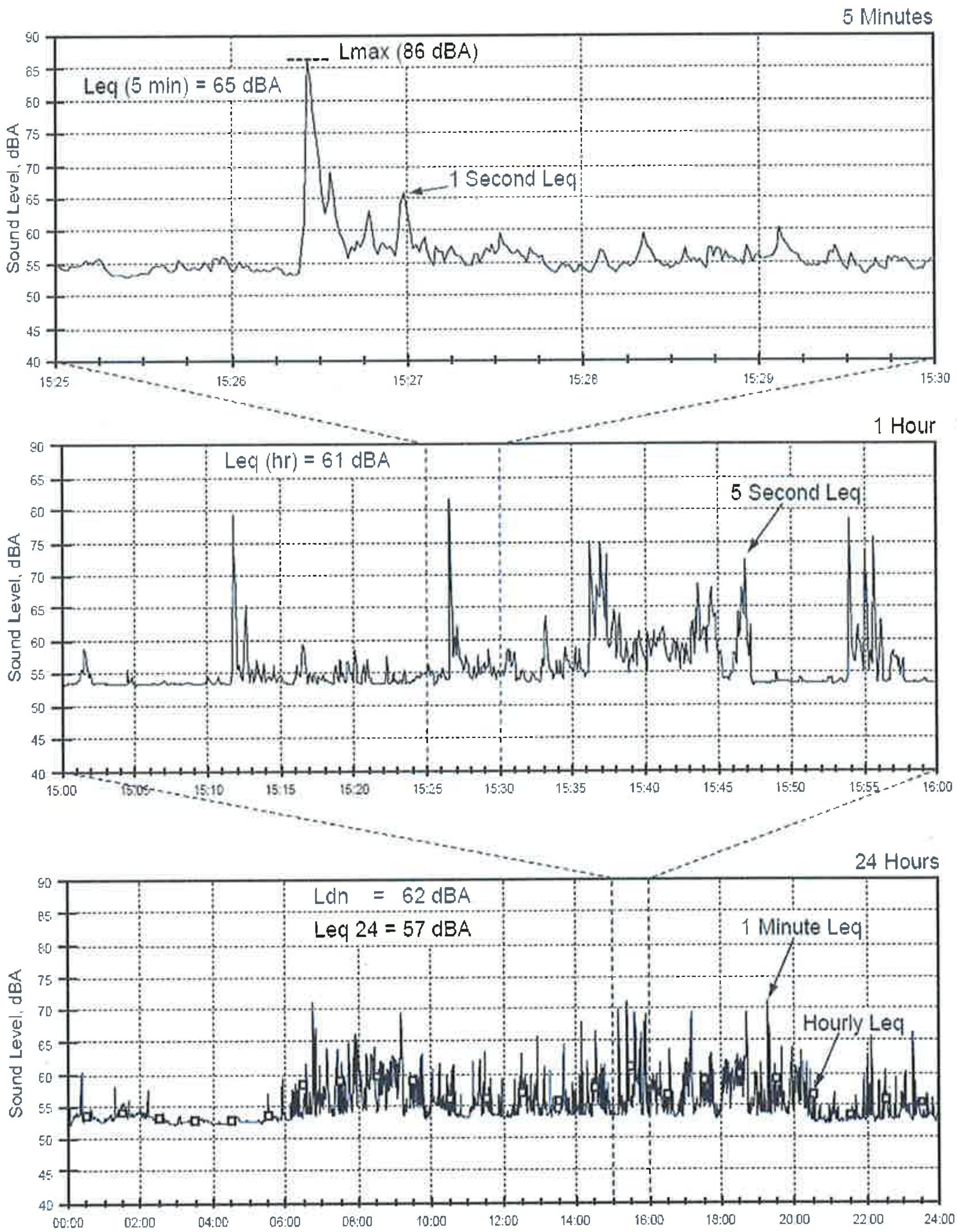
Sound energy is totaled here over a full hour; it accumulates from all noise events during that hour. Subtraction of 35.6 from this one-hour sound exposure converts it into a time average, as explained in Section 1.5.6. In brief, if the actual fluctuating noise were replaced by a constant noise equal to this average value, the same total sound energy would enter the receiver's ears. This type of average value is "equivalent" in that sense to the actual fluctuating noise. A useful, alternative way of computing Leq due to a series of transit noise events is:

$$L_{eq}(\text{hour}) = 10 \log_{10} [\text{Energy Sum of all SELs}] - 35.6$$

This equation concentrates on the cumulative contribution of individual noise events. The bottom frame shows the sound level fluctuations over a full 24 hour period. It is discussed in section 1.5.5.

Fig. 1.10 shows some typical hourly Leq's, both for transit and non-transit sources. As is apparent from the figure, typical hourly Leq's range from the 40s to the 80s. Note that these Leq's depend upon the number of events during the hour and also upon each event's duration, which is affected by vehicle speed. Doubling the number of events during the hour will increase the Leq by 3 decibels, as will doubling the duration of each individual event.

Hourly Leq is adopted here as the measure of cumulative noise impact for non-residential land uses (those not involving sleep) because: (1) Leq's correlate well with speech interference in conversation and on the telephone – as well as interruption of TV, radio and music enjoyment, (2) Leq's increase with the duration of transit events, which is important to people's reaction and (3) Leq's take into account the number of transit events over the hour, which is also important to people's reaction. Section 1.6.6 contains more detail in support of Leq as the adopted descriptor for cumulative noise impact for non-residential land uses.



Typical A-weighted Sound Level Variation over a 24-Hour Period

Figure 1.9, Example A-weighted Sound Level Time Histories

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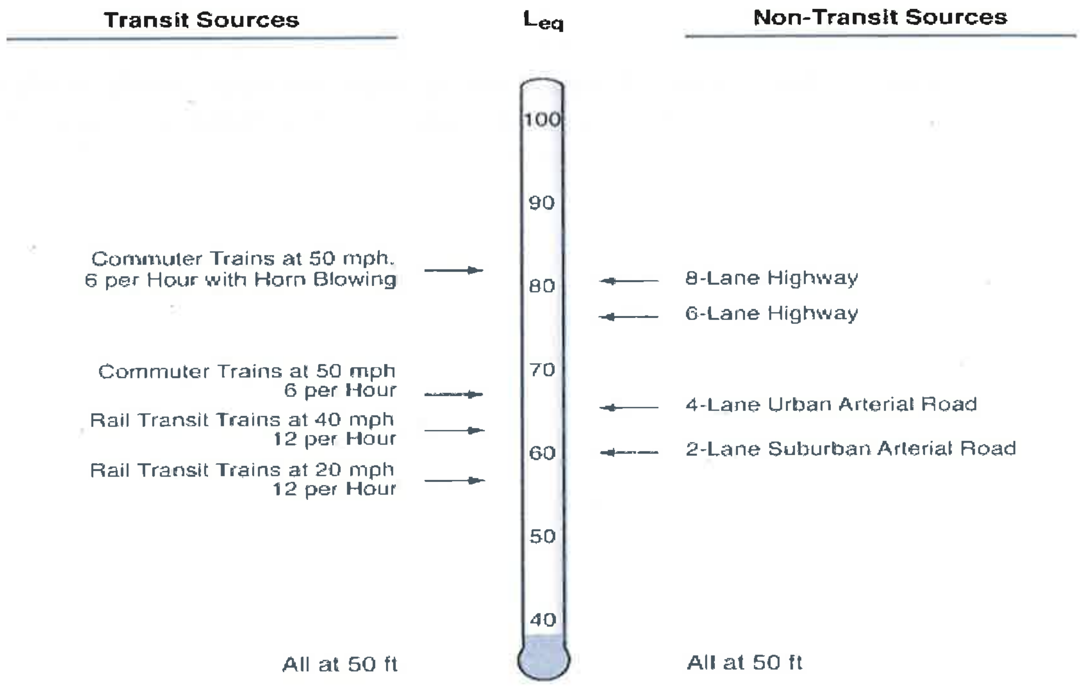

Figure 1.10, Typical Hourly Leq's at 15.2 m

1.6.5 Day-Night Sound Level(Ldn): Cumulative 24- Hour Exposure from all events

The descriptor for cumulative 24-hour exposure is the Day-Night Sound Level, abbreviated here as "Ldn." It is a 24-hour measure that accounts for the moment-to- moment fluctuations in A-Levels due to all sound sources during 24 hours, combined. Such fluctuations are illustrated in the bottom frame of Figure 1.9. Here the area under the curve represents the receiver's noise dose over a full 24 hours. Note that some vehicle passbys occur at night in the figure, when the background noise is less. Mathematically, the Day-Night Level is computed as:

$$L_{dn} = 10 \log_{10} [\text{Total Sound Energy during 24 hours}] - 49.4$$

Where nighttime noise (10pm to 7am) is increased by 10 dB before totaling.

Sound energy is totaled over a full 24 hours; it accumulates from all noise events during that 24 hours. Subtraction of 49.4 from this 24-hour dose converts it into a type of "average," as explained in Section 1.6.6. In brief, if the actual fluctuating noise were replaced by a constant noise equal to this average value, the same total sound energy would enter the receiver's ears.

An alternative way of computing Ldn from 24-hr Leq is:

$$L_{dn} = 10 \log_{10} [\text{Energy sum of 24 hourly Leqs}] - 13.8$$

Where nighttime Leq's are increased by 10 dB before totaling, as in the previous equation.

Ldn due to a series of transit-noise events can also be computed as:

$$L_{dn} = 10 \log_{10} [\text{Energy sum of all SELs}] - 49.4$$

This is assuming that transit noise dominates the 24-hour noise environment. Here again, nighttime SELs are increased by 10 dB before totaling. This equation concentrates upon individual noise events.

Figure 1.11 shows some typical Ldn's, both for transit and non-transit sources. As is apparent from the figure, typical Ldn's range from the 50s to the 70s – where 50 is a quiet 24-hour period and 70 is an extremely loud one. Note that these Ldn's depend upon the number of events during day and night separately – and also upon each event's duration, which is affected by vehicle speed.

Ldn is adopted here as the measure of cumulative noise impact for residential land uses (those involving sleep), because: (1) Ldn correlates well with the results of attitudinal surveys of residential noise impact (2) Ldn's increase with the duration of transit events, which is important to people's reaction, (3) Ldn's take into account the number of transit events over the full twenty-four hours, which is also important to people's reaction, (4) Ldn's take into account the increased sensitivity to noise at night, when most people are asleep, (5) Ldn's allow composite measurements to capture all sources of community noise combined, (6) Ldn's allow quantitative comparison of transit noise with all other community noises, (7) Ldn has wide acceptance internationally. Section 1.6.6 contains more detail in support of Ldn as the adopted descriptor for cumulative noise impact for residential land uses.

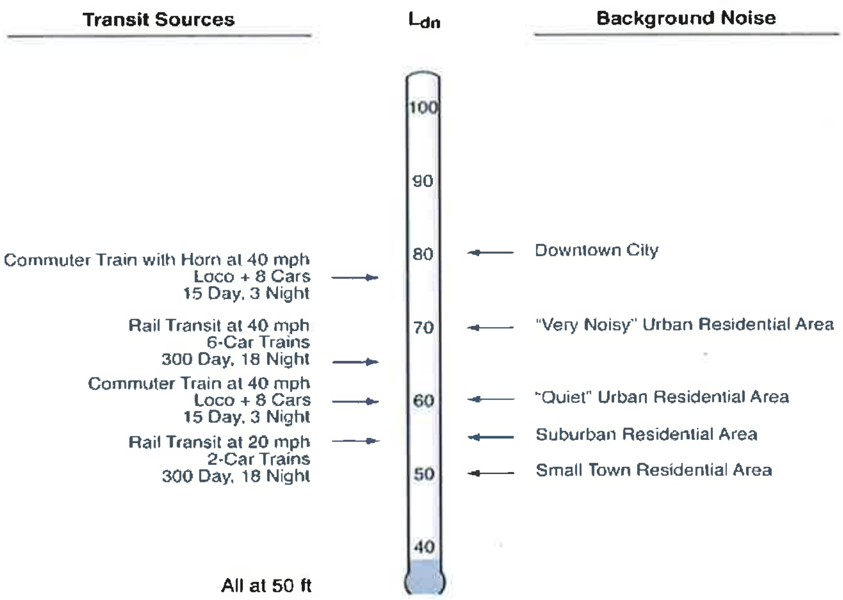

Figure 1.11, Typical Ldn's measured at 15.2 m

1.6.6 A Noise Exposure Analogy for Leq and Ldn

In Figure 1.9, the area under the curves represents noise exposure. An analogy between rainfall and noise is sometimes helpful to further explain these noise exposures.

The one-hour noise time history in the middle frame of the figure is analogous to one hour of rainfall, that is, the total accumulation of rain over this one-hour period. Note that every rain shower increases the one-hour accumulation. Also, note that heavier showers increase the amount more than do lighter ones, and longer showers increase the amount more than shorter ones. The same is true for noise:

(1) every transit event increases the one-hour noise exposure; (2) loud events increase the noise exposure more than do quieter ones; and (3) events that stretch out longer in time increase the noise exposure more than shorter ones.

Unfortunately, the word "average" leaves many people with the impression that the maximum levels which attract their attention are being devalued or ignored. They are not. Just as all the rain that falls in the rain gauge in one hour counts toward the total, all sounds are included in the one-hour noise exposure that underlies Leq and in the 24-hour noise exposure that underlies Ldn. None of the noise is being ignored, even though the Leq and Ldn are often numerically lower than many maximum A-weighted Sound Levels. Noise exposure includes all transit events, all noise levels that occur during their time periods -- without exception. Every added event, even the quiet ones, will increase the noise exposure, and therefore increase Leq and Ldn.

Neither the Leq nor the Ldn is an "average" in the normal sense of the word, where introduction of a quiet event would pull down the average. Further, similar to the effect of rainfall in watering a field or garden, scientific evidence strongly indicates that total noise exposure is the truest measure of noise impact. Neither the moment-to-moment rain rate nor the moment-to-moment A-level noise is a good measure of long-term effects.

It is pertinent to ask why not just compute transit noise impact on the basis of the highest Lmax of the day, for example, as "loudest Lmax equals 90 dBA?" If that were done, then there would be no difference in noise impact between a main trunk line and a suburban branch line; one passby per day would be no better than 100 per day, if the loudest level remained unchanged. Both Leq and Ldn increase with the number of passbys, while Lmax does not. Both the Leq and the Ldn combine the number of passbys with each passby's Lmax and duration, all into a cumulative noise exposure, with mathematics that make sense from an annoyance point of view. Leq and Ldn mathematics produce results that correlate well with independent tests of noise annoyance from all types of noise sources.

In terms of individual passbys, some characteristics of both Leq and Ldn are given as under:

When passby Lmax's increase:	→ Both Leq and Ldn increase
When passby durations increase:	→ Both Leq and Ldn increase
When the number of passbys increases:	→ Both Leq and Ldn increase
When some operations shift to louder vehicles:	→ Both Leq and Ldn increase
When passbys shift from day to night:	→ Ldn increases

All of these increases in Leq and Ldn correlate to increase in community annoyance.

1.7 NOISE SCREENING PROCEDURE, GENERAL & DETAILED ANALYSIS

For carrying out noise screening, general and detailed analysis of air-borne noise, chapters 4, 5 and 6 of FTA Manual can be referred to. Mitigation measures for radiated noise are discussed in chapter-7 of this document.

Chapter-2

Ground Borne Vibrations and Noise - Basic Concepts

2.1 Ground-borne vibration can be a major concern for nearby neighbors of a transit system route or maintenance facility, causing buildings to shake and rumbling sounds to be heard. In contrast to airborne noise, ground-borne vibration is not a common environmental problem. Some common sources of ground-borne vibration are trains, buses on rough roads, and construction activities such as blasting, pile-driving and operating heavy earth-moving equipment.

The effects of ground-borne vibration include perceivable movement of the building floors, rattling of windows, shaking of items on shelves or hanging on walls, and rumbling sounds. In extreme cases, the vibration can cause damage to buildings, though it is an uncommon phenomenon as a result of regular train operations, with the occasional exception of blasting and pile-driving during construction. Annoyance from vibration often occurs when the vibration exceeds the threshold of perception by only a small margin. A vibration level that causes annoyance will be well below the damage threshold for normal buildings.

The basic concepts of ground-borne vibration are illustrated for a rail system in Fig. 2.1. The train wheels rolling on the rails create vibration energy that is transmitted through the track support system into the transit structure. The amount of energy that is transmitted into the transit structure is strongly dependent on factors such as how smooth the wheels and rails are and the resonance frequencies of the vehicle suspension system and the track support system. These systems, like all mechanical systems, have resonances which result in increased vibration response at certain frequencies, called natural frequencies

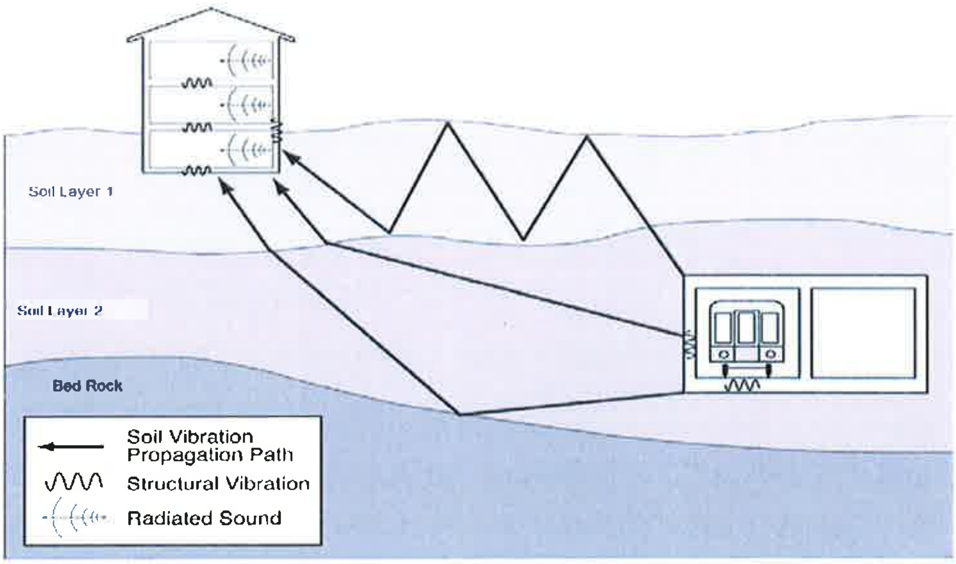

Fig. 2.1 Propagation of ground borne vibration into buildings

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The vibration of the transit structure excites the adjacent ground, creating vibration waves that propagate through the various soil and rock strata to the foundations of nearby buildings. The vibration propagates from the foundation throughout the remainder of the building structure. The maximum vibration amplitudes of the floors and walls of a building often will be at the resonance frequencies of various components of the building.

The vibration of floors and walls may cause perceptible vibration, rattling of items such as windows or dishes on shelves, or a rumble noise. The rumble is the noise radiated from the motion of the room surfaces. In essence, the room surfaces act like a giant loudspeaker causing what is called ground-borne noise.

It is important to note that ground-borne vibration is mostly never annoying to people who are outdoors. Although the motion of the ground may be perceived, without the effects associated with the shaking of a building, the motion does not provoke the same adverse human reaction. In addition, the rumble noise that usually accompanies the building vibration is perceptible only inside buildings.

2.2 DESCRIPTORS OF GROUND-BORNE VIBRATION AND NOISE

2.2.1 Vibratory Motion

Vibration is an oscillatory motion which can be described in terms of the displacement, velocity, or acceleration. Because the motion is oscillatory, there is no net movement of the vibration element and the average of any of the motion descriptors is zero. Displacement is the easiest descriptor to understand. For a vibrating floor, the displacement is simply the distance that a point on the floor moves away from its static position. The velocity represents the instantaneous speed of the floor movement and acceleration is the rate of change of that speed.

Although displacement is easier to understand than velocity or acceleration, it is rarely used for describing ground-borne vibration. Most transducers used for measuring ground-borne vibration use either velocity or acceleration. Further, the response of humans, buildings, and equipment to vibration is more accurately described using velocity or acceleration.

2.2.2 Amplitude Descriptors

Vibration consists of rapidly fluctuating motions with an average motion of zero. Several descriptors can be used to quantify vibration amplitude, two of which are shown in Figure 2.2. The raw signal is the lighter-weight curve in the top graph. This curve shows the instantaneous vibration velocity which fluctuates positive and negative about the zero point. The peak particle velocity (PPV) is defined as the maximum instantaneous positive or negative peak of the vibration signal. PPV is often used in monitoring of blasting vibration since it is related to the stresses that are experienced by buildings. Although peak particle velocity is appropriate for evaluating the potential of building damage, it is not suitable for evaluating human response. It takes some time for the human body to respond to vibration signals. In a sense, the human body responds to an average vibration amplitude. Because the net average of a vibration signal is zero, the root mean square (rms) amplitude is used to describe the "smoothed" vibration amplitude. The root mean square of a signal is the square root of the average of the squared amplitude of the signal. The average is typically over a one second period. The rms amplitude is shown superimposed on the vibration signal in fig. 2.2. The rms amplitude is always less than the PPV and is always positive.

The PPV and rms velocity are normally described in meters per second and vibration in decibel.

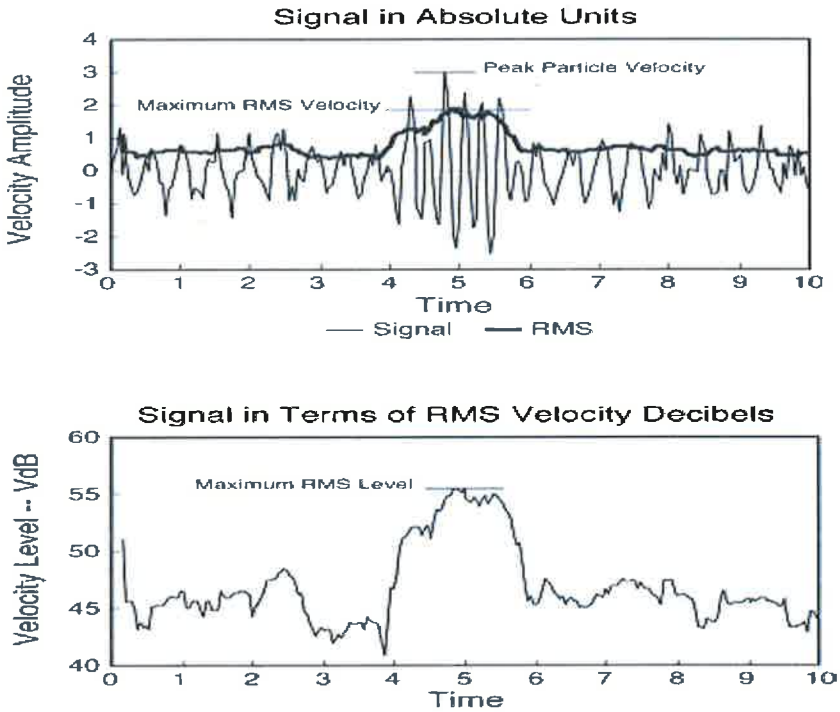


Fig. 2.2, Different methods of Describing a Vibration Signal

Decibel notation acts to compress the range of numbers required to describe vibration. The bottom graph in Figure 2.2 shows the rms curve of the top graph expressed in decibels. Vibration velocity level in decibels is defined as:

$$Lv = 20 \times \log_{10} \{ V/V_{ref} \}$$

Where "Lv" is the velocity level in decibels, "v" is the rms velocity amplitude, and "vref" is the reference velocity amplitude. A reference must always be specified whenever a quantity is expressed in terms of decibels. The accepted reference quantities for vibration velocity are 2.54×10^{-8} meters /second in the USA and either 1×10^{-8} meters/second or 5×10^{-8} meters/second in the rest of the world. Because of the variations in the reference quantities, it is important to be clear about what reference quantity is being used whenever velocity levels are specified. All vibration levels in this document are referenced to 2.54×10^{-8} meter/sec. Although not a universally accepted notation, the abbreviation "VdB" is used in this document for vibration decibels to reduce the potential for confusion with sound decibels.

2.2.3 Ground-Borne Noise

As discussed above, the rumbling sound caused by the vibration of room surfaces is called ground-borne noise. The annoyance potential of ground-borne noise is usually characterized with the A-weighted sound level. Although the A-weighted level is almost the only metric used to characterize community noise, there are potential problems when characterizing low-frequency noise using A-weighting. This is because of the non-linearity of human hearing which causes sounds dominated by low-frequency components to seem louder than broadband sounds that have the same A-weighted level. The result is that ground-borne noise with a level of 40 dBA sounds louder than 40 dBA broadband noise or high frequency air borne noise. This is accounted for by setting the limits or threshold values for ground-borne noise lower than would be the case for broadband or high frequency noise.

2.3 HUMAN PERCEPTION OF GROUND-BORNE VIBRATION & NOISE

This section discussed general background on human response to different levels of building vibration, laying the groundwork for the criteria for ground-borne vibration and noise that are presented in subsequent chapter.

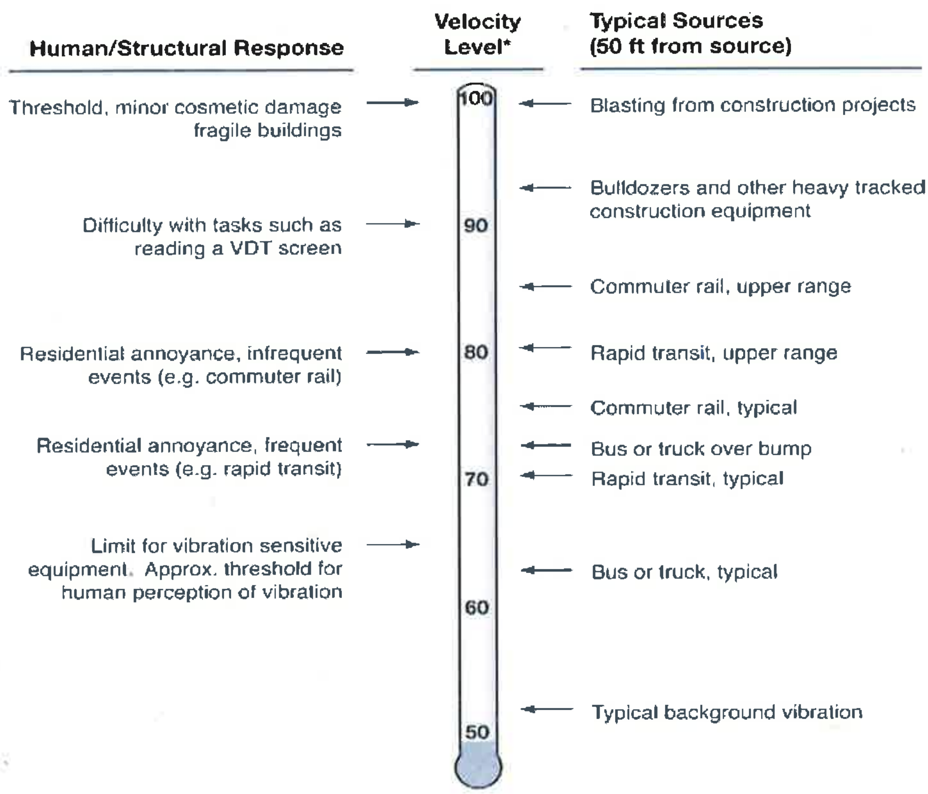
2.3.1 Typical Levels of Ground-Borne Vibration and Noise

Based on the detailed research done in United States, in contrast to airborne noise, ground-borne vibration is not a phenomenon that most people experience every day. The background vibration velocity level in residential areas is usually 50 VdB or lower, well below the threshold of perception for humans which is around 65 VdB. Most perceptible indoor vibration is caused by sources within buildings such as operation of mechanical equipment, movement of people or slamming of doors. Typical outdoor sources of perceptible ground-borne vibration are construction equipment, steel-wheeled trains, and traffic on rough roads. If the roadway is smooth, the vibration from traffic is rarely perceptible.

Figure 2.3 indicates common vibration sources and the human and structural response to ground-borne vibration. The range of interest is from approximately 50 VdB to 100 VdB. Background vibration is usually well below the threshold of human perception and is of concern only when the vibration affects very sensitive manufacturing or research equipment. Electron microscopes and high-resolution lithography equipment are typical of equipment that is highly sensitive to vibration.

Although the perceptibility threshold is about 65 VdB, human response to vibration is not usually significant unless the vibration exceeds 70 VdB. Rapid transit or light rail systems typically generate vibration levels of 70 VdB or more near their tracks. On the other hand, buses and trucks rarely create vibration that exceeds 70 VdB unless there are bumps in the road. Because of the heavy locomotives on diesel commuter rail systems, the vibration levels average about 5 to 10 decibels higher than rail transit vehicles. If there is unusually rough road or track, wheel flats, geologic conditions that promote efficient propagation of vibration, or vehicles with very stiff suspension systems, the vibration levels from any source can be 10 decibels higher than typical.

Hence, at 15.2 meters (50 feet), the upper range for rapid transit vibration is around 80 VdB and the high range for commuter rail vibration is 85 VdB. If the vibration level in a residence reaches 85 VdB, most people will be strongly annoyed by the vibration.



** RMS Vibration Velocity Level in VdB relative to 10^{-6} inches/second*

Figure 2.3, Typical Levels of Ground-Borne Vibration

The relationship between ground-borne vibration and ground-borne noise depends on the frequency content of the vibration and the acoustical absorption of the receiving room. The more acoustical absorption in the room, the lower will be the noise level. For a room with average acoustical absorption, the unweighted sound pressure level is approximately equal to the average vibration velocity level of the room surfaces.* Hence, the A-weighted level of ground-borne noise can be estimated by applying A-weighting to the vibration velocity spectrum. Since the A-weighting at 31.5 Hz is -39.4 dB, if the vibration spectrum peaks at 30 Hz, the A-weighted sound level will be approximately 40 decibels lower than the velocity level. Correspondingly, if the vibration spectrum peaks at 60 Hz, the A-weighted sound level will be about 25 decibels lower than the velocity level.

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*The sound level approximately equals the average vibration velocity level *only* when the velocity level is referenced to 1 micro inch/second (2.54×10^{-8} m/s). When velocity level is expressed using Vref of 1×10^{-8} m/sec, the sample calculation to work out sound level is given as under:

Say Lv ($v_{ref} \sim 2.54 \times 10^{-8}$ m/s)=100, then what is Lv($v_{ref} \sim 1 \times 10^{-8}$ m/s) ?

Lv= $20 \times \log_{10}(2.54 \times 10^{-8} / 1 \times 10^{-8}) = 20 \times \log_{10}(2.54) = 8.09$ say 8 dBv, thus Lv($v_{ref} \sim 1 \times 10^{-8}$ m/s) = 100+8 = 108 dBv and vice versa.

Table 2.1 describes the human response to different levels of ground-borne noise and vibration. The first column is the vibration velocity level, and the next two columns are for the corresponding noise level assuming that the vibration spectrum peaks at 30 Hz or 60 Hz. As discussed above, the A-weighted noise level will be approximately 40 dB less than the vibration velocity level if the spectrum peak is around 30 Hz, and 25 dB lower if the spectrum peak is around 60 Hz. Table 2.1 illustrates that achieving either the acceptable vibration or acceptable noise levels does not guarantee that the other will be acceptable. For example, the noise caused by vibrating structural components may be very annoying even though the vibration cannot be felt. Alternatively, a low-frequency vibration could be annoying while the ground- borne noise level it generates is acceptable

Table 2.1 Human Response to Different Levels of Ground-Borne Noise and Vibration

Vib. Velocity Level	Noise Level		Human Response
	Low Freq1	Mid Freq2	
65 VdB	25 dBA	40 dBA	Approximate threshold of perception for many humans. Low-frequency sound usually inaudible, mid-frequency sound excessive for quiet sleeping areas.
75 VdB	35 dBA	50 dBA	Approximate dividing line between barely perceptible and distinctly perceptible. Many people find transit vibration at this level annoying. Low-frequency noise acceptable for sleeping areas, mid-frequency noise annoying in most quiet occupied areas
85 VdB	45 dBA	60 dBA	Vibration acceptable only if there are an infrequent number of events per day. Low-frequency noise annoying for sleeping areas, mid-frequency noise annoying even for infrequent events with institutional land uses such as schools and churches.

Notes:
1. Approximate noise level when vibration spectrum peak is near 30 Hz.
2. Approximate noise level when vibration spectrum peak is near 60 Hz.

2.4 GROUND-BORNE VIBRATION FOR DIFFERENT TRANSPORT MODES

The brief discussion about typical problems with ground-borne vibrations and noise for different modes of transit is as under:

2.4.1 **Steel-Wheel Urban Rail Transit**: This category includes both heavy rail transit and light rail transit. Heavy rail is generally defined as electrified rapid transit trains with dedicated guide-way, and light rail as electrified transit trains that do not require dedicated guide-way e.g. trams. The ground-borne vibration characteristics of heavy and light rail vehicles are very similar since they have similar suspension systems and axle loads. Most of the studies of ground-borne vibration had been done in the Unites States focused on urban rail transit. Problems with ground-borne vibration and noise are common when there is less than 15 m distance between a subway structure and building foundations. Whether the problem will be perceptible vibration or audible noise is strongly dependent on local geology and the structural details of the building. Complaints about ground-borne vibration from surface track are more common than complaints about ground-borne noise. A significant percentage of complaints about both ground- borne vibration and noise can be attributed to the proximity of special track-work, rough or corrugated track, or wheel flats.

2.4.2 **Commuter and Intercity Passenger Trains:** This category includes passenger trains powered by diesel or electric locomotives. In terms of vibration effects at a single location, the major difference between commuter and intercity passenger trains is that the latter are on a less frequent schedule. Both often share track with goods trains, which have quite different vibration characteristics than the first category discussed above. The locomotives usually create the highest vibration levels. There is the potential of vibration-related problems anytime that new commuter or intercity rail passenger service is introduced in an urban or suburban area.

2.4.3 **High Speed Passenger Trains:** High-speed passenger trains have the potential of creating high levels of ground-borne vibration. Ground-borne vibration should be anticipated as one of the major environmental impacts of any high-speed train located in an urban or suburban area.

2.4.4 **Goods (Freight) Trains:** Local and long-distance freight trains are similar in that they both are diesel or electrical powered and have the same types of cars. They differ in their overall length, number and size of locomotives, and number of heavily loaded cars. Locomotives and rail cars with wheel flats are of the highest vibration levels. Because locomotive suspensions are similar, the maximum vibration levels of local and long-distance freights are similar. It is not uncommon for freight trains to be the source of intrusive ground-borne vibration. All such new freight corridors planned in suburban areas with proper study about their noise and vibration impact.

2.4.5 **Automated Guide-Way Transit Systems (AGT):** This transit mode encompasses a wide range of transportation vehicles providing local circulation in main city areas, airports and theme parks. In general, ground-borne vibration can be expected to be generated by steel-wheel/steel-rail system when limited in size. Because AGT systems normally operate at low speeds, have lightweight vehicles, and rarely operate in vibration-sensitive areas, ground-borne vibration problems are very rare.

2.5 FACTORS INFLUENCING GROUND-BORNE VIBRATION & NOISE

One of the major problems in developing accurate estimates of ground-borne vibration is the large number of factors that can influence the levels at the receiver position. This section discusses a general appreciation of which factors have significant effects on the levels of ground-borne vibration. Table 2.2 is a summary of some of the many factors that are known to have, or are suspected of having, a significant influence on the levels of ground-borne vibration and noise. As discussed in the earlier sections, the physical parameters of the transit facility, the geology, and the receiving building all influence the vibration levels. The important physical parameters can be divided into following four categories:

2.5.1 **Operational and Vehicle Factors:** This category includes all the parameters that relate to the vehicle and operation of the trains. Factors such as high speed, stiff primary suspensions on the vehicle, and flat or worn wheels will increase the possibility of problems from ground-borne vibration.

2.5.2 **Guide-Way:** The condition of the rails; the type of guide-way; the rail support system e.g. fastenings, sleepers; and the mass and stiffness of the guide-way structure will all have an influence on the level of ground-borne vibration. Jointed rail, worn rail, and wheel impacts at locations like points & crossings, can all cause substantial increase in ground-borne vibration. A rail system guide-way will be either underground (subway), at-grade, or elevated. It is rare for ground-borne vibration to be a problem with elevated railways except when guide-way supports are located within 15.2 meters of buildings. For guide-ways at-grade, directly radiated (air-borne) noise is usually the dominant problem, although vibration can also be a problem. For underground, ground- borne vibration is often one of the most important environmental problems. For rubber-tired systems, the smoothness of the roadway/guide-way is the critical factor; if the surface is smooth, vibration problems are unlikely.

2.5.3 **Geology:** Soil and subsurface conditions are known to have a strong influence on the levels of ground-borne vibration. Among the most important factors are the stiffness and internal damping of the soil and the depth to bedrock. Experience with ground-borne vibration is such that vibration propagation is more efficient in stiff clay soils, and shallow rock seems to concentrate the vibration energy close to the surface and can result in ground-borne vibration problems at large distances from the track. Factors such as layering of the soil and depth to water table can have significant effects on the propagation of ground-borne vibration.

2.5.4 **Receiving Buildings:** It is important to note that the receiving building is a key component in the evaluation of ground-borne vibration since ground-borne vibration problems occur almost exclusively inside buildings. The train vibration may be perceptible to people who are outdoors, but it is very rare for outdoor vibration to cause complaints. The vibration levels inside a building are dependent on the vibration energy that reaches the building foundation, the coupling of the building foundation to the soil, and the propagation of the vibration through the building. The general guideline is that the heavier a building is, the lower the response will be to the incident vibration energy.

Table 2.2. Factors that Influence Levels of Ground-Borne Vibration and Noise

Factors Related to Vibration Source	
Factors	**Influence**
Vehicle Suspension	If the suspension is stiff in the vertical direction, the effective vibration forces will be higher. On transit cars, only the primary suspension affects the vibration levels, the secondary suspension that supports the car body has no apparent effect.
Wheel Type and Condition	Use of pneumatic tires is one of the best methods of controlling ground-borne vibration. Normal resilient wheels on rail transit systems are usually too stiff to provide significant vibration reduction. Wheel flats and general wheel roughness are the major cause of vibration from steel wheel/steel rail systems.
Track/Road-way Surface	Rough track or rough roads are often the cause of vibration problems. Maintaining a smooth surface will reduce vibration levels.
Track Support System	On rail systems, the track support system is one of the major components in determining the levels of ground-borne vibration. The highest vibration levels are created by track that is rigidly attached to a concrete track bed (e.g. track on wood half-sleepers embedded in the concrete). The vibration levels are much lower when special vibration control track systems such as resilient fasteners, ballast mats and floating slabs are used.
Speed	As intuitively expected, higher speeds result in higher vibration levels. Doubling speed usually results in a vibration level increase of 4 to 6 decibels.
Transit Structure	The general rule-of-thumb is that the heavier the transit structure, the lower the vibration levels. The vibration levels from a lightweight bored tunnel will usually be higher than from a poured concrete box subway.
Depth of Vibration source	There are significant differences in the vibration characteristics when the source is underground compared to surface level.
Factors Related to Vibration Path	
Factor	**Influence**
Soil Type	Vibration levels are generally higher in stiff clay-type soils than in loose sandy soils.
Rock Layers	Vibration levels are usually high near at-grade track when the depth to bedrock is about 9 m e t e r s (30 feet) or less. Subways/Tunnels founded in rock will result in lower vibration amplitudes close to the subway due to efficient propagation, as the vibration level does not attenuate as rapidly in rock as it does in soil.
Soil Layering	Soil layering will have a substantial, but unpredictable, effect on the vibration levels since each stratum can have significantly different dynamic characteristics.
Depth to Water Table	The presence of the water table may have a significant effect on ground-borne vibration, but a definite relationship has not been established.
Factors Related to Vibration Receiver	
Factor	**Influence**
Foundation Type	The general rule-of-thumb is that the heavier the building foundation, the greater the coupling loss as the vibration propagates from the ground into the building.
Building Construction	Since ground-borne vibration and noise are almost always evaluated in terms of indoor receivers, the propagation of the vibration through the building must be considered. Each building has different characteristics relative to structure-borne vibration, although the general rule-of-thumb is the more massive the building, the lower the levels of ground-borne vibration.
Acoustical Absorption	The amount of acoustical absorption in the receiver room affects the levels of ground-borne noise.

Chapter-3

Noise and Vibration Impact Assessment Criteria

3.1 This chapter presents the criteria to be used in evaluating noise and vibration from metro transit projects. Section 3.2 provides criteria for environmental noise and 3.3 for ground borne vibration and noise.

3.2 ENVIRONMENTAL NOISE CRITERIA

In India, the noise pollution is governed by "The Noise Pollution (Regulation and control) Rules, 2000". As per Para 11(vi) of the Act, railway locomotives enjoy a statutory protection under the Indian Railway Act. 1989 against any action for the noise created thereby. There is no provision in the Act which provides for regulation of noise by railway locomotives. Section 16 of the Act gives statutory authority for the use of locomotives to railway administration.

Due to nature of rail operation, noise levels close to metro rail line, at-grade or elevated, normally consist of relatively short periods of high noise levels separated by longer periods of quiet. In order to assess potential rail noise effects, it is important to consider the overall rail noise exposure during day as well as night hours. The noise criteria recommended by various authorities including the one in India are discussed and criteria for metro rail transit corridors in India are recommended.

3.2.1 Noise Pollution Standards in India

The ambient air quality standards in respect of noise in different areas /zones have been notified by the Ministry of Environment & Forests, Government of India vide 'The Noise Pollution (Regulation and Control) Rules, 2000. The Schedule of ambient air quality standards in respect of noise notified in the above 'Rules' is reproduced below:

Table 3.1: Ambient Air Quality standards in respect of Noise

Area Code	Category of Area/Zone	Limits in dB(A) Leq	
		Day time	Night time
(A)	Industrial area	75	70
(B)	Commercial area	65	55
(C)	Residential area	55	45
(D)	Silence Zone	50	40

Note:

1. Day time shall mean 6.00 a.m. to 10.00 p.m.
2. Night time shall mean from 10.00 p.m. to 6.00.a.m.
3. Silence zone is defined as an area comprising not less than 100 meters around hospitals, educational institutions and courts. The silent zones are zones which are declared as such by the competent authority.
4. Mixed categories of areas may be declared as one of the four above-mentioned categories by the competent authority.
5. dB(A) Leq denotes the time weighted average of the level of sound in decibels on scale A, Leq being energy mean of the noise level over a specific period.

3.2.2 Standards as per APTA Manual

TCRP Report 23 of APTA (American Public Transport Authority) provides following values as guidelines for maximum airborne noise from train operations.

Table 3.2: Maximum air-borne noise from Train operations as per APTA Manual

Community Area Category	Description	Single Even Maximum Noise Level Design Goal - dBA		
		Single family Dwellings	Multi-Family Dwellings	Commercial Buildings
I	Low Density Residential	70	75	80
II	Average Density	75	75	80
III	High Density Residential	75	80	85
IV	Commercial	80	80	85
V	Industrial/ Highway	80	85	85

Note: These limits apply at the structures or sensitive area, but not closer than 15.2 meters

3.2.3 General Standards as per FTA Manual

For general standards, FTA manual refers to criteria recommended by FHWA (Federal High Way Administration, USA), various categories of activities wise, taking into consideration only the loudest-hour or worst-hour noise levels. These are reproduced as follows:

Table 3.3 FHWA Noise Abatement Criteria

Activity Category	Hourly A-weighted Sound Level (dBA)		Description of Activity Category
	Leq(h)	L10(h)	
A	57 Exterior	60 Exterior	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B	67 Exterior	70 Exterior	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals.
C	72 Exterior	75 Exterior	Developed lands, properties, or activities not included in Categories A or B above.
D	--	--	Undeveloped lands.
E	52 Interior	55 Interior	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.

Note: Noise mitigation must be studied where predicted traffic noise levels approach or exceed the values in this table. Individual state highway agencies define "approach or exceed" within their states. As a result, the actual criteria that trigger mitigation studies are all 1 to 3 decibels lower than the values in this table. Contact specific state highway agencies to learn their definition of "approach or exceed."

3.2.4 FTA Manual Criteria for areas where ambient noise level is higher than General Standards

As per extensive studies done by US Federal Transit Administration, the train noise generally need to be more than 3 dB over and above the background noise levels to be perceptible. Allowable noise levels exposure for different levels of existing noise exposure as per FTA manual is given in table 3.4 as under:

Table 3.4. Noise Impact Criteria: Effect on Cumulative Noise Exposure

Ldn or Leq in dBA (rounded to nearest whole decibel)

Existing Noise Exposure	Allowable Project Noise Exposure	Allowable Combined Total Noise Exposure	Allowable Noise Exposure Increase
45	51	52	7
50	53	55	5
55	55	58	3
60	57	62	2
65	60	66	1
70	64	71	1
75	65	75	0

The above table indicates that increase greater than shown above will cause Moderate Impact. This table shows that as the existing noise exposure increases from 45 dBA to 75 dBA, the allowed transit noise exposure increases from 51 dBA to 65 dBA. However, the allowed increase in the cumulative noise level decreases from 7 dBA to 0dBA (rounded to the nearest whole decibel). The justification for this is based on the fact that people already exposed to high levels of noise tolerate only a small increase in the amount of noise in their community. In contrast, if the existing noise levels are quite low, it is reasonable to allow a greater change in the community noise for the equivalent difference in annoyance. It should be noted that these criteria are based on general community reactions to noise at varying levels which have been documented in scientific literature by US Federal Transit Administration and other institutions and do not account for specific community attitudinal factors which may exist.

3.2.5 Recommendations for Metro Rail Transit Systems for India

3.2.5.1 *Standards in areas where ambient noise levels are low*

Since Government of India has already notified the permissible noise levels taking the environmental concerns of the country which are only at small variation compared to recommendations in the APTA Manual, it is proposed to retain the same for Metro systems in India.

Since Metro trains generally do not run during 10 pm to 6 am, day time limits are proposed as the limits for environmental noise and tabulated in table 3.5.

Table 3.5: Recommended Criteria for air-borne noise

Activity/Area Category	Category of Area/Zone	Limits in dB(A) L_{deq}
A	Industrial area	75
B	Commercial area	65
C	Residential area	55
D	Silence Zone	50

L_{deq} refers to the equivalent noise level during day time (from 6 am to 10 pm)

3.2.5.2 ***Standards in areas where ambient noise levels are high***

Keeping in view the standards recommended for permissible noise levels above, FTA manual criteria in table 3.1 and the high urban noise levels already existing in most cities in India, the recommended noise levels are tabulated in Table 3.6 (a). The noise criteria and descriptors depend on land use.

Table 3.6 (a): Recommended noise levels in areas depend on land use.

Existing Noise Exposure Leq(h) or Ldn (dBA)	Project Noise Impact Exposure, * Leq(h) or Ldn (dBA)					
	Category 1 or 2 Sites			Category 3 Sites		
	No Impact	Moderate Impact	Severe Impact	No Impact	Moderate Impact	Severe Impact
<43	<ambient+ 10	Ambient+ 10 to 15	>Ambient+ 15	<Ambient+ 15	Ambient+ 15 to 20	>Ambient+ 20
43	<52	52-58	>58	<57	57-63	>63
44	<52	52-58	>58	<57	57-63	>63
45	<52	52-58	>58	<57	57-63	>63
46	<53	53-59	>59	<58	58-64	>64
47	<53	53-59	>59	<58	58-64	>64
48	<53	53-59	>59	<58	58-64	>64
49	<54	54-59	>59	<59	59-64	>64
50	<54	54-59	>59	<59	59-64	>64
51	*<54*	*54-60*	*>60*	*<59*	*59-65*	*>65*
52	<55	55-60	>60	<60	60-65	>65
53	<55	55-60	>60	<60	60-65	>65
54	<55	55-61	>61	<60	60-66	>66
55	<56	56-61	>61	<61	61-66	>66
56	<56	56-62	>62	<61	61-67	>67
57	<57	57-62	>62	<62	62-67	>67
59	<58	58-63	>63	<63	63-68	>68
60	<58	58-63	>63	<63	63-68	>68
61	<59	59-64	>64	<64	64-69	>69
62	<59	59-64	>64	<64	64-69	>69
63	<60	60-65	>65	<65	65-70	>70
64	<61	61-65	>65	<66	66-70	>70

65	<61	61-66	>66	<66	66-71	>71
66	<62	62-67	>67	<67	67-72	>72
67	<63	63-67	>67	<68	68-72	>72
68	<63	63-68	>68	<68	68-73	>73
69	<64	64-69	>69	<69	69-74	>74
70	<65	65-69	>69	<70	70-74	>74
71	<66	66-70	>70	<71	71-	>75
72	<66	66-71	>71	<71	71-	>76
73	<66	66-71	>71	<71	71-	>76
74	<66	66-72	>72	<71	71-77	>77
75	<66	66-73	>73	<71	71-	>78
76	<66	66-74	>74	<71	71-	>79
77	<66	66-74	>74	<71	71-	>79
>77	<66	66-75	>75	<71	71-	>80
*Ldn is used for land use where nighttime sensitivity is a factor; Leq during the hour of maximum transit noise exposure is used for land use involving only daytime activities.						

Any increase greater than the levels shown in table 3.6 (a) is considered to cause moderate impact, and should be attenuated.

Note: Para 3.2 of FTA manual may be referred for detailed understanding on application of Noise Impact Criteria.

Table 3.6 (b). Land Use Categories and Metrics for Transit Noise Impact Criteria

Land Use Category	Noise Metric (dBA)	Description of Land Use Category
1	Outdoor Leq(h)*	Tracts of land where quiet is an essential element in their intended purpose. This category includes lands set aside for serenity and quiet, and such land uses as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use. Also included are recording studios and concert halls.
2	Outdoor Ldn	Residences and buildings where people normally sleep. This category includes homes, hospitals and hotels where a nighttime sensitivity to noise is assumed to be of utmost importance.
3	Outdoor Leq(h)*	Institutional land uses with primarily daytime and evening use. This category includes schools, libraries, theaters, and churches where it is important to avoid interference with such activities as speech, meditation and concentration on reading material. Places for meditation or study associated with cemeteries, monuments, museums, campgrounds and recreational facilities can also be considered to be in this category. Certain historical sites and parks are also included.
* Leq for the noisiest hour of transit-related activity during hours of noise sensitivity.		

3.2.5.3 *Defining the Level of Impact*

The noise impact criteria are defined by two curves which allow increasing project noise levels as existing noise increases up to a point, beyond which impact is determined based on project noise alone. Below the lower curve in Figure 3.6 (c), a proposed project is considered to have no noise impact since, on the average, the introduction of the project will result in an insignificant increase in the number of people highly annoyed by the new noise. The curve defining the onset of noise impact stops increasing at 65 dB for Category 1 and 2 land use, a standard limit for an acceptable living environment defined by a number of agencies in USA and similar analogy may apply in Indian conditions. Project noise above the upper curve is considered to cause Severe Impact since a significant percentage of people may be highly annoyed by the new noise. As per FTA, this curve flattens out at 75 dB for Category 1 and 2 land use, a level associated with an unacceptable living environment. As indicated by the right-hand scale on Figure 3.6 (c), the project noise criteria are 5 decibels higher for Category 3 land uses since these types of land use are considered to be slightly less sensitive to noise than the types of land use in categories 1 and 2.

Between the two curves the proposed project is judged to have Moderate Impact. The change in the cumulative noise level is noticeable to most people, but may not be sufficient to cause strong, adverse reactions from the community. In this transitional area, other project-specific factors must be considered to determine the magnitude of the impact and the need for mitigation, such as the existing level, predicted level of increase over existing noise levels and the types and numbers of noise-sensitive land uses affected.

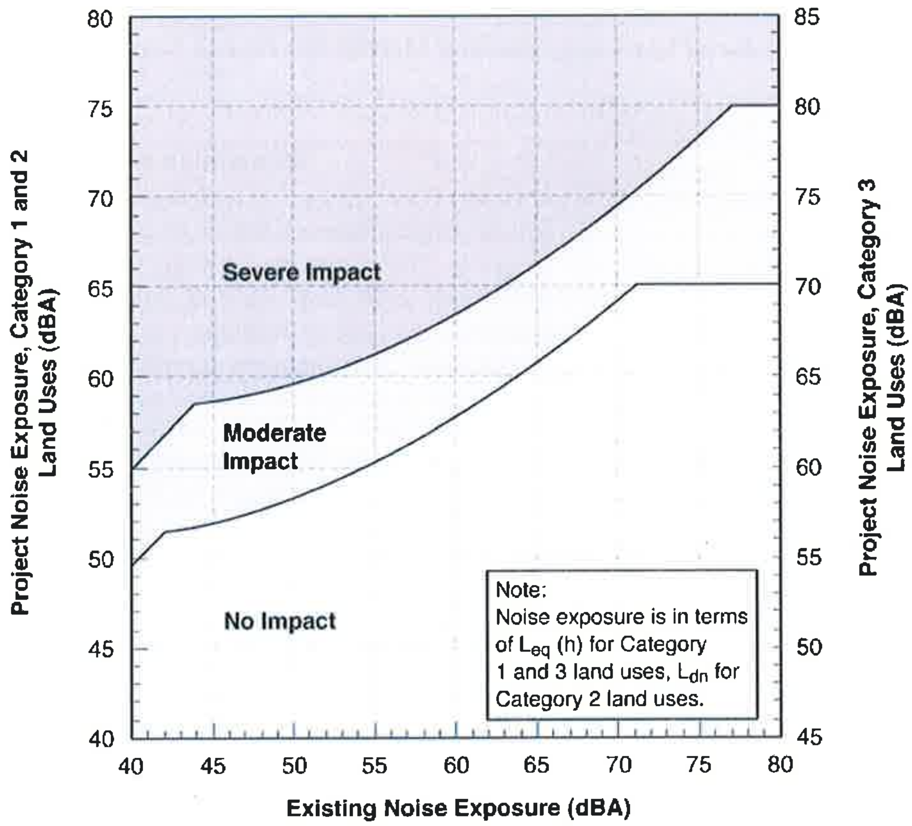

Figure 3.6 (C) Noise Impact Criteria for Transit Projects

3.3 GROUND BORNE VIBRATION & NOISE CRITERIA

3.3.1 International Standards

Summary of standards for Ground-borne noise and vibration as published in "TCRP Web-Only Document 48: As per ISO 2631-1 the frequency range considered for the possible effects of vibration on health, comfort and perception and motion sickness is given as below:

(i) 0.5 Hz to 80 Hz for health, comfort and perception and

(ii) 0.1 Hz to 0.5 Hz for motion sickness

The vibration is perceived in different forms, either body vibration (1 Hz to 80 Hz) or perceived through tactile senses, which have higher frequency range. In usual circumstances, frequencies as low as 16 Hz or as high as 500 Hz may be relevant to the ground borne noise. Typically, dominant frequencies are less than 100 Hz because they represent the response of building elements.

3.3.2 FTA Standards

The criteria for environmental impact from ground-borne vibration and noise are based on the maximum root-mean-square (rms) vibration levels for repeated events of the same source. The criteria presented in Table 3.7 account for variation in project types as well as the frequency of events, which differ widely among transit projects. Most experience is with the community response to ground-borne vibration from rail rapid transit systems with typical headways in the range of 3 to 10 minutes and each vibration event lasting less than 10 seconds. It is intuitive that when there will be many fewer events each day, as is typical for commuter rail projects, it should take higher vibration levels to evoke the same community response. This is accounted for in the criteria by distinguishing between projects with varying numbers of events, where Frequent Events are defined as more than 70 events per day, Occasional Events range between 30 and 70 events per day, and Infrequent Events are fewer than 30 events per day. Most commuter rail branch lines will fall into the infrequent events category, although the trunk lines of some commuter rail lines serving major cities are in the occasional events category.

The criteria for acceptable ground-borne vibration are expressed in terms of rms velocity levels in decibels and the criteria for acceptable ground-borne noise are expressed in terms of A-weighted sound levels. The limits are specified for the three land-use categories defined below:

Vibration Category 1 – High Sensitivity: Included in Category 1 are buildings where vibration would interfere with operations within the building, including levels that may be well below those associated with human annoyance. Concert halls and other special-use facilities are covered separately in Table 3.8. Typical land uses covered by Category 1 are: vibration-sensitive research and manufacturing, hospitals with vibration-sensitive equipment, and university research operations. The degree of sensitivity to vibration will depend on the specific equipment that will be affected by the vibration. Equipment such as electronic microscopes and high resolution lithographic equipment can be very sensitive to vibration, and even normal optical microscopes will sometimes be difficult to use when vibration is well below the human annoyance level. Manufacturing of computer chips is an example of a vibration- sensitive process.

The vibration limits for Vibration Category 1 are based on acceptable vibration for moderately vibration-sensitive equipment such as optical microscopes and electronic microscopes with vibration isolation systems. Defining limits for equipment that is even more sensitive requires a detailed review of the specific equipment involved. This type of review is usually performed during the Detailed Analysis associated with the final design phase and not as part of the environmental impact assessment. Mitigation of transit vibration that affects sensitive equipment typically involves modification of the equipment mounting system or relocation of the equipment rather than applying vibration control measures to the transit project.

It is to be noted that this category does not include most computer installations or telephone switching equipment. Although the owners of this type of equipment often are very concerned about the potential of ground-borne vibration interrupting smooth operation of their equipment, it is rare for computer or other electronic equipment to be particularly sensitive to vibration. Most such equipment is designed to operate in typical building environments where the equipment may experience occasional shock from bumping and continuous background vibration caused by other equipment.

Vibration Category 2 – Residential: This category covers all residential land uses and any buildings where people sleep, such as hotels and hospitals. No differentiation is made between different types of residential areas. This is primarily because ground-borne vibration and noise are experienced indoors and building occupants have practically no means to reduce their exposure. Even in a noisy urban area, the bedrooms often will be quiet in buildings that have effective noise insulation and tightly closed windows. Moreover, in certain cities street traffic often abates at night when trains continue to operate. Hence, an occupant of a bedroom in a noisy urban area is likely to be just as exposed to ground-borne noise and vibration as someone in a quiet suburban area. The criteria apply to the transit-generated ground-borne vibration and noise whether the source is subway/tunnel or surface running trains.

Vibration Category 3 – Institutional: This category includes schools, churches, other institutions, and quiet offices that do not have vibration-sensitive equipment, but still have the potential for activity interference. Although it is generally appropriate to include office buildings in this category, it is not appropriate to include all buildings that have any office space. For example, most industrial buildings have office space, but it is not intended that buildings primarily for industrial use be included in this category.

Table 3.7. Ground-Borne Vibration (GBV) and Ground-Borne Noise (GBN) Impact Criteria for General Assessment

Land Use Category	GBV Impact Levels (VdB ref 25.4 micro-mm /sec)			GBN Impact Levels (dB ref 20 micro Pascals)		
	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]
Category 1: Buildings where vibration would interfere with interior operations.	65 VdB4	65 VdB4	65 VdB4	N/A4	N/A4	N/A4
Category 2: Residences and buildings where people normally sleep	72 VdB	75 VdB	80 VdB	35 dBA	38 dBA	43 dBA
Category 3: Institutional land uses with primarily daytime use.	75 VdB	78 VdB	83 VdB	40 dBA	43 dBA	48 dBA

Notes:

1. " Frequent Events" is defined as more than 70 vibration events of the same source per day. Most rapid transit projects fall into this category.
2. "Occasional Events" is defined as between 30 and 70 vibration events of the same source per day. Most commuter trunk lines have this many operations.
3. "Infrequent Events" is defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.
4. This criterion limit is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes. Vibration-sensitive manufacturing or research will require detailed evaluation to define the acceptable vibration levels. Ensuring lower vibration levels in a building often requires special design of the HVAC systems and stiffened floors.
5. Vibration sensitive equipment is generally not sensitive to ground-borne noise. DIN 4150-2 can also be referred for guidelines values for evaluating human exposure to vibration in dwellings and similar spaces.

There are some buildings, such as concert halls, TV & recording studios and theatres, which can be very sensitive to vibration and noise but do not fit into any of the three categories discussed above. Because of the sensitivity of these buildings, they usually warrant special attention during the environmental assessment of a transit project. Table 3.8 gives criteria for acceptable levels of ground-borne vibration and noise for various types of special buildings.

Table 3-8. Ground-Borne Vibration and Noise Impact Criteria for Special Buildings

Type of Building or Room	Ground-Borne Vibration Impact Levels (VdB re 1 micro-inch/sec)		Ground-Borne Noise Impact Levels (dB re 20 micro-Pascals)	
	Frequent 1 Events	Occasional or Infrequent 2 Events	Frequent 1 Events	Occasional or Infrequent 2 Events
Concert Halls	65 VdB	65 VdB	25 dBA	25 dBA
TV Studios	65 VdB	65 VdB	25 dBA	25 dBA
Recording Studios	65 VdB	65 VdB	25 dBA	25 dBA
Auditoriums	72 VdB	80 VdB	30 dBA	38 dBA
Theaters	72 VdB	80 VdB	35 dBA	43 dBA

Notes:

1. "Frequent Events" is defined as more than 70 vibration events per day. Most rapid transit projects fall into this category.
2. "Occasional or Infrequent Events" is defined as fewer than 70 vibration events per day. This category includes most commuter rail systems.
3. If the building will rarely be occupied when the trains are operating, there is no need to consider impact. As an example, consider locating a commuter rail line next to a concert hall. If no commuter trains will operate after 7 pm, it should be rare that the trains interfere with the use of the hall.

The criteria in Tables 3.7 and 3.8 are related to ground-borne vibration causing human annoyance or interfering with use of vibration-sensitive equipment. It is extremely rare for vibration from train operations to cause any sort of building damage, even minor cosmetic damage. However, there is sometimes concern about damage to fragile historic buildings located near the right-of-way. Even in these cases, damage is unlikely except when the track will be very close to the structure. Damage thresholds that apply to these structures are out of scope of this document.

For cases where there are existing vibration conditions, in most cases the existing environment does not include a significant number of perceptible ground-borne vibration or noise events. The most common example of needing to account for the pre-existing vibration is when the project will be located in an existing rail corridor. When the project will cause vibration more than 5 VdB greater than the existing source, the existing source can be ignored and the standard vibration criteria applied to the project. Following are methods of handling representative scenarios:

(i) Infrequently-used rail corridor (fewer than 5 trains per day): Use the general vibration criteria, Tables 3.7 and 3.8.

(ii) Moderately-used rail corridor (5 to 12 trains per day): If the existing train vibration exceeds the impact criteria given in Tables 3.7 and 3.8, there will be no impact from the project vibration if the levels estimated using the procedures outlined in either Chapter 5 or 6 are at least 5 VdB less than the existing train vibration. Otherwise, vibration criteria in Tables 3.7 and 3.8 apply to the project. The existing train vibration can be either measured or estimated using the General Assessment procedures in Chapter 5. It is usually preferable to measure vibration from existing train traffic.

(iii) Heavily-used rail corridor (more than 12 train per day): If the existing train vibration exceeds the impact criteria given in Tables 3.7 and 3.8, the project will cause additional impact if the project significantly increases the number of vibration events. Approximately doubling the number of events is required for a significant increase. If there is not a significant increase in vibration events, there will be additional impact only if the project vibration, estimated using the procedures of Chapters 5 or 6, will be 3 VdB or more higher than the existing vibration.

(iv) Moving Existing Tracks: Another scenario where existing vibration can be significant is when a new transit project will use an existing railroad right-of- way and result in shifting the location of existing railroad tracks. The track relocation and reconstruction can result in lower vibration levels, in which case this aspect of the project represents a benefit, not an adverse impact. If the track relocation will cause higher vibration levels at sensitive receptors, then the projected vibration levels must be compared to the appropriate impact criterion to determine if there will be new impacts. If impact is judged to have existed prior to moving the tracks, new impact will be assessed only if the relocation results in more than a 3 VdB increase in vibration level.

Ground borne noise impacts are assessed based on criteria for human annoyance and activity interference. The results of the Detailed Analysis provide vibration spectra inside a building. These vibration spectra can be converted to sound pressure level spectra in the occupied spaces using the method described in Chapter 6 (Section 6.2.2). For residential buildings, the criteria for acceptability are given in terms of the A- weighted sound pressure level in Table 3.7. For special buildings listed in Table 3.8, a single-valued level may not be sufficient to assess activity interference at the Detailed Analysis stage. Each special building may have a unique specification for acceptable noise levels. For example, a recording studio may have stringent requirements for allowable noise in each frequency band. Therefore, the ground- borne noise criteria for each sensitive building in this category will have to be determined on a case-by- case basis.

3.3.3 Recommended Standards for Ground-borne Vibration and Noise

In India, no criterion has been prescribed in “The noise Pollution (Regulation and Control) Rules, 2000 regarding the limits of ground borne vibrations and noise on account of railway systems. Metro Rail Transit systems in India have however represented about the complaints of vibrations at some locations near tunnels.

It is seen that the International standards presented in Annexure-A are more or less in agreement with FTA Manual provisions. FTA Manual provides for different standards for different frequency of events. As most metro railway systems in India fall under the category of ‘Frequent Events’, which is defined as more than 70 vibration events per day, FTA standards for ‘Frequent events’ are recommended as the standard for noise and vibration for metro rail systems. These are tabulated in Table 3.9 as follows:

Table 3.9: Recommended Criteria for Ground-borne Vibration & Ground-Borne Noise for General Assessment

Land use category	Ground-borne Vibration Impact Levels (VdB ref=25.4μ mm/s)	Ground-borne Noise Impact Levels (dB ref 20 μ Pa)
Category 1: Buildings where vibration would interfere with interior operations	65 VdB	N/A*
Category 2: Residences and buildings where people normally sleep	72 VdB	35 dBA
Category 3: Institutional land uses with primarily day time use	75 VdB	40 dBA

*Vibration sensitive equipment is not sensitive to ground-borne noise

There are some buildings such as concert halls, TV and recording studios and theatres that can be very sensitive to vibration and noise but do not fit into any of the three categories of table 3.9. Because of the sensitivity of these buildings, they warrant special attention. Table 3.10 recommends criteria for acceptable levels of ground-borne vibration and noise for various special types of such buildings.

Table 3.10: Recommended Criteria for Ground-borne Vibration & Ground-Borne Noise for Special Buildings

Type of building or room	Ground-borne Vibration Impact Levels (VdB ref 25.4μ mm/s)	Ground-borne Noise Impact Levels (A-weighted dB ref 20 μ Pa)
Concert Halls	65 VdB	25 dBA
TV Studios	65 VdB	25 dBA
Recording Studios	65 VdB	25 dBA
Auditoriums	72 VdB	30 dBA
Theaters	72 VdB	35 dBA

3.3.4 Recommended Standards for Ground-borne Vibration and Nosie under existing Vibration Condition

When the project will cause vibration more than 5 VdB greater than the existing source, the existing source can be ignored and the standard vibration criteria given above shall be applicable to the project.

Chapter-4

Vibration Screening Procedure

4.1 The vibration screening procedure is designed to identify projects that have little possibility of creating significant adverse impact. If the screening procedure does not identify any potential problem areas, it is usually safe to eliminate further consideration of vibration impact from the environmental analysis.

4.2 STEPS IN SCREENING PROCEDURE

The steps in the vibration screening procedure are summarized in Figure 4.1 in a flow chart format. Following is a summary of the steps:

Initial Decision: If the project includes any type of steel-wheeled/steel-rail vehicle, there is potential for vibration impact. Proceed directly to the evaluation of screening distances. Transit projects that do not involve vehicles, such as a station rehabilitation, do not have potential for vibration impact unless the track system is modified (e.g., tracks moved or switches modified). Rail systems include urban rapid transit, light rail transit, commuter rail, and steel-wheel intermediate capacity transit systems.

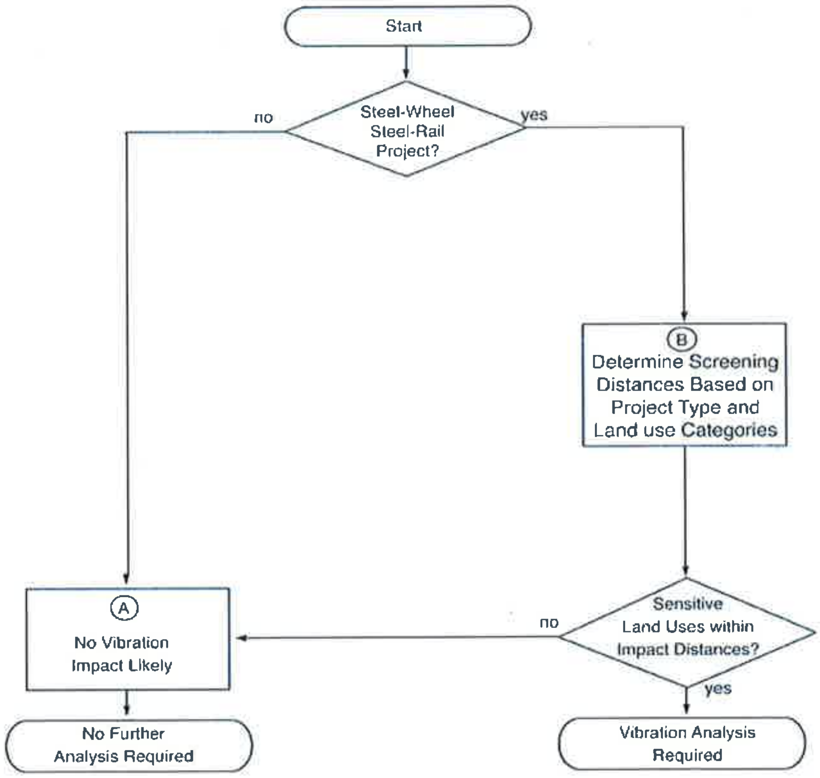

Figure 4.1, Flow chart of Vibration Screening Process

Screening Distances (Box B): If the result of the first step is that there is potential for vibration impact, determine if any vibration-sensitive land uses are within the screening zones. Vibration-sensitive land uses are identified in Chapter 3. Tables 4.1 and 4.2 are used to determine the applicable vibration screening distances for the project.

Impact: If there are any vibration-sensitive land uses within the screening distances, there is the potential for vibration impact. The result of the screening procedure is that a General Vibration Assessment should be done as part of the environmental analysis.

4.3 SCREENING DISTANCES

4.3.1 Project Categories

The project categories for the vibration screening procedure are summarized in Table 4.1 for four types of rail transit.

Table 4.1 Project Types for Vibration Screening Procedure

Project Type	Description
1. Conventional Commuter Railroad	Both the locomotives and the passenger vehicles create significant vibration. The highest vibration levels are usually created by the locomotives. Electric commuter rail vehicles create levels of ground-borne vibration that are comparable to electric rapid transit vehicles.
2. Rail Rapid Transit	Ground-borne vibration impact from rapid transit trains is one of the major environmental issues for new systems. For operation in subway, the ground-borne vibration is usually a significant environmental impact. It is less common for at-grade and elevated rapid transit lines to create intrusive ground-borne vibration.
3. Light Rail Transit	The ground-borne vibration characteristics of light rail systems are very similar to those of rapid transit systems. Because the speeds of light rail systems are usually lower, the typical vibration levels usually are lower. Steel-wheel/steel-rail Automated Guideway Transit (AGT) will fall into either this category or the Intermediate Capacity Transit category depending on the level of service and train speeds.
4. Intermediate Capacity Transit	Because of the low operating speeds of most ICT systems, significant vibration problems are not common. However, steel-wheel ICT systems that operate close to vibration-sensitive buildings have the potential of causing intrusive vibration. With a stiff suspension system, an ICT system could create intrusive vibration.

4.3.2 Distances

The screening distances are given in Table 4.2. These distances are based on the criteria presented in Chapter 3, with a 5-decibel factor of safety included. The distances have been determined using vibration prediction procedures that are summarized in Chapter 5 assuming "normal" vibration propagation. As discussed in Chapter 5, efficient vibration propagation can result in substantially higher vibration levels.

Because of the 5-decibel safety factor, even with efficient propagation, the screening

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distances will identify most of the potentially impacted areas. By not specifically accounting for the possibility of efficient vibration propagation, there is some possibility that some potential impact areas will not be identified in the screening process. When there is evidence of efficient propagation, such as previous complaints about existing transit facilities or a history of problems with construction vibration, the distances in Table 4.2 should be increased by a factor of 1.5.

Table 4.2. Screening Distances (meters) for Vibration Assessment

Type of Project	Critical Distance for Land Use Categories* Distance from Right-of-Way or Property Line		
	Cat. 1	Cat. 2	Cat. 3
Conventional Commuter Railroad	183	61	37
Rail Rapid Transit	183	61	37
Light Rail Transit	138	50	30
Intermediate Capacity Transit	61	30	15

* The land-use categories are defined in Chapter 3. Some vibration-sensitive land uses are not included in these categories. Examples are: concert halls and TV studios which, for the screening procedure, should be evaluated as Category 1; and theaters and auditoriums which should be evaluated as Category 2

Chapter-5

General Vibration Assessment

5.1 This chapter outlines procedures that can be used to develop generalized predictions of ground-borne vibration and noise. This manual includes three different levels of detail for projecting ground-borne vibration:

Screening: The screening procedure is discussed in Chapter 4. A standard table of impact distances is used to determine if ground-borne vibration from the project may affect sensitive land uses. More detailed analysis is required if any sensitive land uses are within the screening distances. The screening procedure does not require any specific knowledge about the vibration characteristics of the system or the geology of the area. If different propagation conditions are known to be present, a simple adjustment is provided.

General Assessment: The general level of assessment, as described in this chapter, is an extension of the screening procedure. It uses generalized data to develop a curve of vibration level as a function of distance from the track. The vibration levels at specific buildings are estimated by reading values from the curve and applying adjustments to account for factors such as track support system, vehicle speed, type of building, and track and wheel condition. The general level deals only with the overall vibration velocity level and the A-weighted sound level. It does not consider the frequency spectrum of the vibration or noise.

Detailed Analysis: Discussed in Chapter 6, the Detailed Analysis involves applying all of the available tools for accurately projecting the vibration impact at specific sites. The procedure outlined in this document includes a test of the vehicle (or similar vehicle) to define the forces generated by the vibration source and tests at the site in question to define how the local geology affects vibration propagation. It is considerably more complex to develop detailed projections of ground-borne vibration than it is to develop detailed projections of airborne noise. Accurate projections of ground - borne vibration require professionals with experience in performing and interpreting vibration propagation tests. As such, detailed vibration predictions are usually performed during the final design phase of a project when there is sufficient reason to suspect adverse vibration impact from the project

There is not always a clear distinction between general and detailed predictions. For example, it is often appropriate to use several representative measurements of vibration propagation along the planned alignment in developing generalized propagation curves. Other times, generalized prediction curves may be sufficient for the majority of the alignment, but with Detailed Analysis applied to particularly sensitive buildings such as a concert hall.

The purpose of the General Assessment is to provide a relatively simple method of developing estimates of the overall levels of ground-borne vibration and noise that can be compared to the acceptability criteria given in Chapter 3. For many projects, particularly when comparing alternatives, this level of detail will be sufficient for the environmental impact assessment. Where there are potential problems, the Detailed Analysis is then undertaken during final design of the selected alternative to accurately define the level of impact and design mitigation measures. A Detailed Analysis will be required when designing special track-support systems such as floating slabs or ballast mats. Detailed Analysis is not usually required if, as is often the case, the mitigation measure consists of relocating a crossover or turnout. Usually, the General Assessment is adequate to determine whether a crossover needs to be relocated.

The basic approach for the General Assessment is to define a curve, or set of curves, that predicts the overall ground-surface vibration as a function of distance from the source, then apply adjustments to these curves to account for factors such as vehicle speed, building type, and receiver location within the building. Figure 5.1 includes curves of vibration level as a function of distance from the source for the common types of vibration sources such as rapid transit trains. When the vehicle type is not covered by the curves included in this section, it will be necessary to define an appropriate curve either by extrapolating from existing information or performing measurements at an existing facility.

5.2 SELECTION OF BASE CURVE FOR GROUND SURFACE VIBRATION LEVEL

The base curves for two standard transportation systems are defined in Figure-5.1. This figure shows typical ground-surface vibration levels assuming equipment in good condition and speeds of 80 Kmph for the rail systems. The levels must be adjusted to account for factors such as different speeds and different geologic conditions than assumed. The adjustment factors are discussed in Section 5.3.

The curves in Figure 5.1 are based on measurements of ground-borne vibration at representative North American transit systems. The top curve applies to trains that are powered by diesel or electric locomotives. It includes intercity passenger trains and commuter rail trains. The curve for rapid transit rail cars covers both heavy and light- rail vehicles on at-grade and subway/tunnel track. It is somewhat surprising that subway and at-grade track can be represented by the same curve since ground-borne vibration created by a train operating in a subway has very different characteristics than vibration from at- grade track. However, in spite of these differences, the overall vibration velocity levels are comparable. Subways tend to have more vibration problems than at-grade track. This is probably due to two factors: (1) subways are usually located in more densely developed areas, and (2) the airborne noise is usually a more serious problem for at-grade systems than the ground-borne vibration. Another difference between subway and at-grade track is that the ground-borne vibration from subways tends to be higher frequency than the vibration from at-grade track, which makes the ground-borne noise more noticeable.

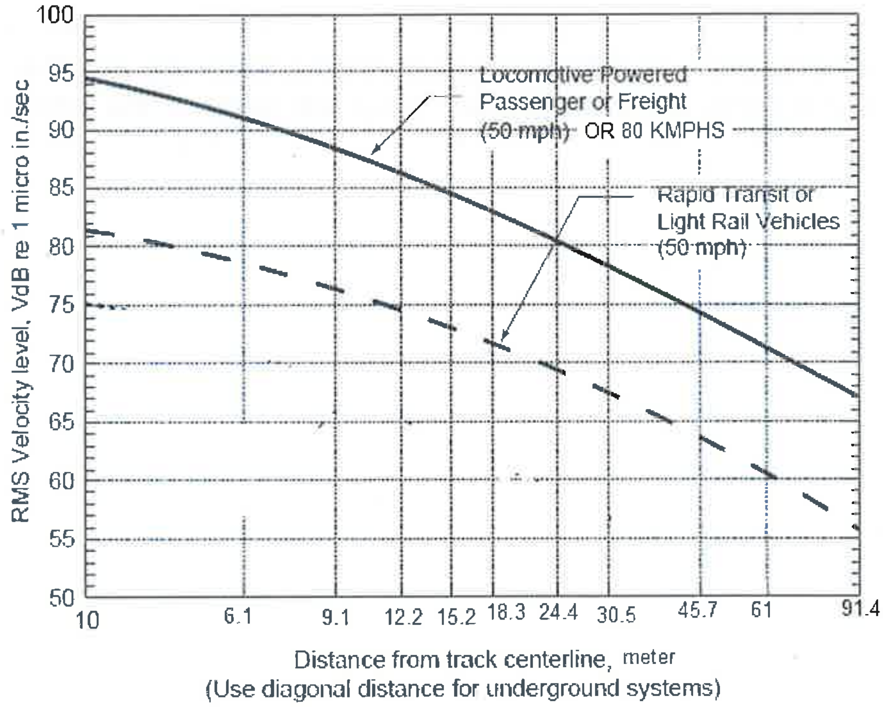

Figure 5.1, Generalized Ground Surface Vibration Curve.

The curves in Figure 5.1 were developed from many measurements of ground-borne vibration. Experience with ground-borne vibration data is that, for any specific type of transit mode, a significant variation in vibration levels under apparently similar conditions is not uncommon. The curves in Figure 5.1 represent the upper range of the measurement data from well-maintained systems. Although actual levels fluctuate widely, it is rare that ground-borne vibration will exceed the curves in Figure 5.1 by more than one or two decibels unless there are extenuating circumstances, such as wheel- or running- surface defects.

One approach to dealing with the normal fluctuation is to show projections as a range. For example, the projected level from Figure 5.1 for an LRT system with train speeds of 80 kmph is about 72 VdB at a distance of 18.3 mts from the track centerline, just at the threshold for acceptable ground-borne vibration for residential land uses. To help illustrate the normal fluctuation, the projected level of ground-borne vibration might be given as 67 to 72 VdB. This approach is not recommended since it tends to confuse the interpretation of whether or not the projected vibration levels exceed the impact threshold. However, because actual levels of ground-borne vibration will sometimes differ substantially from the projections, some care must be taken when interpreting projections. Some guidelines are given below:

1. Projected vibration is below the impact threshold. Vibration impact is unlikely in this case.

2. Projected ground-borne vibration is 0 to 5 decibels greater than the impact threshold. In this range there is still a significant chance that actual ground-borne vibration levels will be below the impact threshold. In this case, the

impact would be reported in the environmental document as exceeding the applicable threshold and a commitment would be made to conduct more detailed studies to refine the vibration impact analysis during final design and determine appropriate mitigation, if necessary. A site-specific Detailed Analysis may show that vibration control measures are not needed.

3. Projected ground-borne vibration is 5 decibels or more greater than the impact threshold. Vibration impact is probable and Detailed Analysis will be needed during final design to help determine appropriate vibration control measures.

The two most important factors that must be accounted for in a General Assessment are the type of vibration source (the mode of transit) and the vibration propagation characteristics. It is well known that there are situations where ground-borne vibration propagates much more efficiently than normal. The result is unacceptable vibration levels at distances two to three times the normal distance. Unfortunately, the geologic conditions that promote efficient propagation have not been well documented and are not fully understood. Shallow bedrock or stiff clay soil often are involved. One possibility is that shallow bedrock acts to keep the vibration energy near the surface. Much of the energy that would normally radiate down is directed back towards the surface by the rock layer with the result that the ground surface vibration is higher than normal.

The selection of a base curve depends on the mode of rail transit under consideration. Appropriate correction factors are then added to account for any unusual propagation characteristics. For less common modes such as magnetically-levitated vehicles (maglev), monorail, or automated guide way transit (AGT), it is necessary to either make a judgment about which curve and adjustment factors best fit the mode or to develop new estimates of vibration level as a function of distance from the track. Consideration for selecting a base curve are discussed as under:

- **Subway/Tunnel Heavy Rail**: Complaints about ground-borne vibration are more common near subways/tunnels than near at-grade track. This is not because subways create higher vibration levels than at-grade systems - rather it is because subways are usually located in high-density areas in close proximity to building foundations. When applied to subways, the rapid transit curve in Figure 5.1 assumes a relatively lightweight bored concrete tunnel in soil. The vibration levels will be lower for heavier subway structures such as cut-and-cover box structures and stations.

- **At-Grade Heavy Rail or LRT**: The available data show that heavy rail and light rail transit vehicles create similar levels of ground-borne vibration. This is not surprising since the vehicles have similar suspension systems and axle loads. Light-rail systems tend to have fewer problems with ground borne vibration because of the lower operating speeds. Similar to the subway case, a adjustment factor must be used if the transit vehicle has a primary suspension that is stiff in the vertical direction.

- **Intermediate Capacity Transit:** The vibration levels created by an intermediate capacity transit system or an AGT system will depend on whether the vehicles have steel wheels or rubber wheels. If they have steel wheels, the transit car curve in Figure 5.1 should be used with appropriate adjustments for operating speed.

5.3 ADJUSTMENTS

Once the base curve has been selected, the adjustments in Table 5.1 can be used to develop vibration projections for specific receiver positions inside buildings. All of the adjustments are given as single numbers to be added to, or subtracted from, the base level. The adjustment parameters are speed, wheel and rail type and condition, type of track support system, type of building foundation, and number of floors above the basement level. It should be recognized that many of these adjustments are strongly dependent on the frequency spectrum of the vibration source and the frequency dependence of the vibration propagation. The single number values are suitable for generalized evaluation of the vibration impact and vibration mitigation measures since they are based on typical vibration spectra. However, the single number adjustments are not adequate for detailed evaluations of impact of sensitive buildings or for detailed specification of mitigation measures. Detailed Analysis requires consideration of the relative importance of different frequency components.

Table 5.1. Adjustment Factors for Generalized Predictions of Ground-Borne Vibration and Noise				
Factors Affecting Vibration Source				
Source Factor	**Adjustment to Propagation Curve**			**Comment**
		Reference Speed		
Speed	Vehicle Speed 97 Kmph 80 Kmph 64 Kmph 48 Kmph 32Kmph	80 Kmph +1.6 dB 0.0 dB -1.9 dB -4.4 dB -8.0 dB	48Kmph +6.0 dB +4.4 dB +2.5 dB 0.0 dB -3.5 dB	Vibration level is approximately proportional to 20*log(speed/speedref). Sometimes the variation with speed has been observed to be as low as 10 to 15 log(speed/speedref).
Vehicle Parameters (not additive, apply greatest value only)				
Vehicle with stiff primary suspension	+8 dB			Transit vehicles with stiff primary suspensions have been shown to create high vibration levels. Include this adjustment when the primary suspension has a vertical resonance frequency greater than 15 Hz.
Resilient Wheels	0 dB			Resilient wheels do not generally affect ground-borne vibration except at frequencies greater than about 80 Hz.
Worn Wheels or Wheels with Flats	+10 dB			Wheel flats or wheels that are unevenly worn can cause high vibration levels. This can be prevented with wheel truing and slip-slide detectors to prevent the wheels from sliding on the track.
Track Conditions (not additive, apply greatest value only)				
Worn or Corrugated Track	+10 dB			If both the wheels and the track are worn, only one adjustment should be used. Corrugated track is a common problem. Mill scale on new rail can cause higher vibration levels until the rail has been in use for some time.
Special Trackwork	+10 dB			Wheel impacts at special trackwork will significantly increase vibration levels. The increase will be less at greater distances from the track.
Jointed Track or Uneven Road Surfaces	+5 dB			Jointed track can cause higher vibration levels than welded track. Rough roads or expansion joints are sources of increased vibration for rubber-tire transit.
Track Treatments (not additive, apply greatest value only)				
Floating Slab Track-bed	-15 dB			The reduction achieved with a floating slab trackbed is strongly dependent on the frequency characteristics of the vibration.
Ballast Mats	-10 dB			Actual reduction is strongly dependent on frequency of vibration.
Resilient/ High-Resilience Fasteners	-5 dB			Slab track with track fasteners that are very compliant in the vertical direction can reduce vibration at frequencies greater than 40 Hz.

Table 5.1. Adjustment Factors for Generalized Predictions of Ground-Borne Vibration and Noise (Continued)		
Factors Affecting Vibration Path		
Path Factor	**Adjustment to Propagation Curve**	**Comment**
Resiliently Supported Ties	-10 dB	Resiliently supported tie systems have been found to provide very effective control of low-frequency vibration.
Track Configuration (not additive, apply greatest value only)		
Type of Transit Structure	Relative to at-grade tie & ballast: Elevated structure -10 dB Open cut 0 dB	The general rule is the heavier the structure, the lower the vibration levels. Putting the track in cut may reduce the vibration levels slightly. Rock- based subways generate higher-frequency vibration.
	Relative to bored subway tunnel in soil: Station -5 dB Cut and cover -3 dB Rock-based - 15 dB	
Ground-borne Propagation Effects		
Geologic conditions that promote efficient vibration propagation	Efficient propagation in soil +10 dB	Refer to the text for guidance on identifying areas where efficient propagation is possible.
	Propagation in rock layer — **Dist.** / **Adjust.**: 15.2 m +2 dB 30.5 m +4 dB 45.7 m +6 dB 61 m +9 dB	The positive adjustment accounts for the lower attenuation of vibration in rock compared to soil. It is generally more difficult to excite vibrations in rock than in soil at the source.
Coupling to building foundation	Wood Frame Houses -5 dB 1-2 Story Masonry -7 dB 3-4 Story Masonry -10 dB Large Masonry on Piles -10 dB Large Masonry on Spread Footings -13 dB Foundation in Rock 0 dB	The general rule is the heavier the building construction, the greater the coupling loss.
Factors Affecting Vibration Receiver		
Receiver Factor	**Adjustment to Propagation Curve**	**Comment**
Floor-to-floor attenuation	1 to 5 floors above grade: -2 dB/floor 5 to 10 floors above grade: -1 dB/floor	This factor accounts for dispersion and attenuation of the vibration energy as it propagates through a building.
Amplification due to resonances of floors, walls, and ceilings	+6 dB	The actual amplification will vary greatly depending on the type of construction. The amplification is lower near the wall/floor and wall/ceiling intersections.
Conversion to Ground-borne Noise		
Noise Level in dBA	Peak frequency of ground vibration: Low frequency (<30 Hz): -50 dB Typical (peak 30 to 60 Hz): -35 dB High frequency (>60 Hz): -20 dB	Use these adjustments to estimate the A-weighted sound level given the average vibration velocity level of the room surfaces. See text for guidelines for selecting low, typical or high frequency characteristics. Use the high-frequency adjustment for subway tunnels in rock or if the dominant frequencies of the vibration spectrum are known to be 60 Hz or greater.

It is important to note that without careful consideration of the shape of the actual vibration spectra, an inappropriate vibration control measure is likely to be selected which can cause an increase in the vibration levels.

The following guidelines are used to select the appropriate adjustment factors. Note that the adjustments for wheel and rail condition are not cumulative. The general rule-of-thumb to use when more than one adjustment may apply is to apply only the largest adjustment. For example: the adjustment for jointed track is 5 decibels and the adjustment for wheel flats is 10 decibels. In an area where there is jointed track and many vehicles have wheel flats, the projected vibration levels should be increased by 10 decibels, not 15 decibels.

- **Train Speed**: The levels of ground-borne vibration and noise vary approximately as 20 times the logarithm of speed. This means that doubling train speed will increase the vibration levels approximately 6 decibels and halving train speed will reduce the levels by 6 decibels. Table 5.1 tabulates the adjustments for reference vehicle speeds of 48 kmph for rubber-tired vehicles and 80 kmph for steel-wheel vehicles. The following relationship should be used to calculate the adjustments for other speeds.

$$\text{Adjustment (dB)} = 20 \times \log_{10} (\text{speed}/\ \text{speed}_{ref})$$

- **Vehicle:** The most important factors for the vehicles are the suspension system, wheel condition, and wheel type. Most new heavy rail and light rail vehicles have relatively soft primary suspensions. However, experience in Atlanta, New York, and other cities has demonstrated that a stiff primary suspension (vertical resonance frequency greater than 15 Hz) can result in higher than normal levels of ground-borne vibration. Vehicles for which the primary suspension consists of a rubber or neoprene "donut" around the axle bearing usually have a very stiff primary suspension with a vertical resonance frequency greater than 40 Hz.

Deteriorated wheel condition is another factor that will increase vibration levels. It can be assumed that a new system will have vehicles with wheels in good condition. However, when older vehicles will be used on new track, it may be appropriate to include an adjustment for wheel condition. The reference curves account for wheels without defects, but wheels with flats or corrugations can cause vibration levels that are 10 VdB higher than normal. Resilient wheels will reduce vibration levels at frequencies greater than the effective resonance frequency of the wheel. Because this resonance frequency is relatively high, often greater than 80 Hz, resilient wheels usually have only a marginal effect on ground-borne vibration. It is important to use only one of the adjustments in this category, the greatest one that applies.

- **Track System and Support**: This category includes the type of rail (welded, jointed or special track work), the track support system, and the condition of the rail. The base curves all assume good condition welded rail. Jointed rail causes higher vibration levels than welded rail; higher amounting depending on the condition of the joints. The wheel impacts at special track work, such as frogs at crossovers, create much higher vibration forces than normal. Because of the higher vibration levels at special track work, crossovers often end up being the principal areas of vibration impact on new systems. Modifying the track support system is one method of mitigating the vibration impact. Special track support systems such as ballast mats, high- resilience track fasteners, resiliently supported ties, and floating slabs have all been shown to be effective in reducing vibration levels.

The condition of the running surface of the rails can strongly affect vibration levels. Factors such as corrugations, general wear, or mill scale on new track can cause vibration levels that are 5 to 15 decibels higher than normal. Mill scale will usually wear off after some time in service; however, the track must be ground to remove corrugations or to reduce the roughness from wear. Again, apply only one of the adjustments.

· **Transit Structure**: The weight and size of a transit structure affects the vibration radiated by that structure. The general rule-of-thumb is that vibration levels will be lower for heavier transit structures. Hence, the vibration levels from a cut- and-cover concrete double-box subway can be assumed to be lower than the vibration from a lightweight concrete-lined bored tunnel. The vibration from elevated structures is lower than from at-grade track because of the mass and damping of the structure and the extra distance that the vibration must travel before it reaches the receiver. Elevated structures in automated guide way transit applications sometimes are designed to bear on building elements. These are a special case and may require detailed design considerations.

· **Propagation Characteristics**: In the General Assessment it is necessary to make a selection among the general propagation characteristics. For a subway, the selection is a fairly straightforward choice of whether or not the subway will be founded in bedrock. Bedrock is considered to be hard rock. It is usually appropriate to consider soft siltstone and sandstone to be more similar to soil than hard rock. As seen in Table 5.1, whether the subway is founded in soil or rock can be a 15 VdB difference in the vibration levels.

When considering at-grade vibration sources, the selection is between "normal" vibration propagation and "efficient" vibration propagation. Efficient vibration propagation results in approximately 10 decibels higher vibration levels. This more than doubles the potential impact zone for ground-borne vibration. One of the problems with identifying the cause of efficient propagation is the difficulty in determining whether higher than normal vibration levels are due to geologic conditions or due to special source conditions (e.g. rail corrugations or wheel flats).

Although it is known that geologic conditions have a significant effect on the vibration levels, it is rarely possible to develop more than a broad-based understanding of the vibration propagation characteristics for a General Assessment. The conservative approach would be to use the 10-decibel adjustment for efficient propagation to evaluate all potential vibration impact. The problem with this approach is that it tends to greatly overstate the potential for vibration impact. Hence, it is best to review available geological data and any complaint history from existing transit lines and major construction sites near the transit corridor to identify areas where efficient propagation is possible. If there is any reason to suspect efficient propagation conditions, then a Detailed Analysis during final design would include vibration propagation tests at the areas identified as potentially efficient propagation sites.

Some geologic conditions are repeatedly associated with efficient propagation. Shallow bedrock, less than 10 m below the surface, is likely to have efficient propagation. Other factors that can be important are soil type and stiffness. In particular, stiff clayey soils have sometimes been associated with efficient vibration propagation. Investigation of soil boring records can be used to estimate depth to bedrock and the presence of problem soil conditions.

A factor that can be particularly complex to address is the effect of vibration propagation through rock. There are three factors from Table 5.1 that need to be included when a subway structure will be founded in rock. First is the -15 decibel adjustment in the "Type of Transit Structure" category. Second is the adjustment based on the propagation distance in the "Geologic Conditions" category. This positive adjustment is applied to the distances shown in Figure 5.1; the adjustment increases with distance because vibration attenuates more slowly in rock than in the soil used as a basis for the reference curve. The third factor is in the "Coupling to Building" category. When a building foundation is directly on the rock layer, there is no "coupling loss" due to the weight and stiffness of the building. Use the standard coupling factors if there is at least a 3 m layer of soil between the building foundation and the rock layer.

- **Type of Building and Receiver Location in Building:** Since annoyance from ground-borne vibration and noise is an indoor phenomenon, the effects of the building structure on the vibration must be considered. Wood frame buildings, such as the typical residential structure, are more easily excited by ground vibration than heavier buildings. In contrast, large masonry buildings with spread footings have a low response to ground vibration. Vibration generally reduces in level as it propagates through a building. As indicated in Table 5.1, a 1- to 2- decibel attenuation per floor is usually assumed. Counteracting this, resonances of the building structure, particularly the floors, will cause some amplification of the vibration. Consequently, for a wood-frame structure, the building-related adjustments nearly cancel out. The adjustments for the first floor assuming a basement are: -5 decibels for the coupling loss; -2 decibels for the propagation from the basement to the first floor; and +6 decibels for the floor amplification. The total adjustment in this case is -1 decibel.

- **Vibration to Ground-Borne Noise Adjustment**: It is possible to estimate the levels of radiated noise given the average vibration amplitude of the room surfaces (floors, walls and ceiling), and the total acoustical absorption in the room. The unweighted sound pressure level is approximately equal to the vibration velocity level when the velocity level is referenced to 2.54×10^{-6} cm/second. However, to estimate the A-weighted sound level from the velocity level, it is necessary to have some information about the frequency spectrum. The A-weighting adjustment drops rapidly at low frequencies, reflecting the relative insensitivity of human hearing to low frequencies. For example, A- weighting is -16 dB at 125 Hz, -26 dB at 60 Hz and -40 dB at 30 Hz. Table 5.1 provides adjustments for vibration depending on whether it has low-frequency, typical or high-frequency characteristics. Some general guidelines for classifying the frequency characteristics are:

- **Low Frequency**: Low-frequency vibration characteristics can be assumed for subways surrounded by cohesion-less sandy soil or whenever a vibration isolation track support system will be used. Low-frequency characteristics can be assumed for most surface track.
- **Typical**: The typical vibration characteristic is the default assumption for subways. It should be assumed for subways until there is information indicating that one of the other assumptions is appropriate. It should be used for surface track when the soil is very stiff with a high clay content.
- **High Frequency**: High-frequency characteristics should be assumed for subways whenever the transit structure is founded in rock or when there is very stiff clayey soil.

5.4 INVENTORY OF VIBRATION IMPACTED LOCATIONS

This chapter includes generalized curves for surface vibration for different transit modes along with adjustments to apply for specific operating conditions and buildings. The projected levels are then compared with the criteria in Chapter 3 to determine whether vibration impact is likely. The results of the General Assessment are expressed in terms of an inventory of all sensitive land uses where either ground-borne vibration or ground-borne noise from the project may exceed the impact thresholds. The General Assessment may include a discussion of mitigation measures which would likely be needed to reduce vibration to acceptable levels.

The purpose of the procedure is to develop a reasonably complete inventory of the buildings that may experience ground-borne vibration or noise that exceed the impact criteria. At this point, it is preferable to make a conservative assessment of the impact. That is, it is better to include some buildings where ground-borne vibration may be below the impact threshold than to exclude buildings where it may exceed the impact threshold. The inventory should be organized according to the categories described in Chapter 3. For each building where the projected ground-borne vibration or noise exceeds the applicable impact threshold, one or more of the vibration control options from Chapter 7 should be considered for applicability. See Section 6.4 for a more complete description of how the General Vibration Assessment fits into the overall procedure.

Chapter-6

Detailed Vibrations Analysis

The goal of the Detailed Analysis is to use all available tools to develop accurate projections of potential ground-borne vibration impact and, when necessary, to design mitigation measures. This is appropriate when the General Assessment has indicated impact and the project has entered the final design and engineering phase. It may also be appropriate to perform a Detailed Analysis at the outset when there are particularly sensitive land uses within the screening distances. Detailed Analysis will require developing estimates of the frequency components of the vibration signal, usually in terms of 1/3-octave-band spectra. Analytical techniques for solving vibration problems are complex and the technology continually advances. Therefore, the approach presented in this chapter focuses on the key steps usually taken by a professional in the field for the guidance of the users.

Three examples in which a detailed vibration analysis may be needed are:

Example 1: A particularly sensitive building such as a major concert hall is within the impact zone. A Detailed Analysis would ensure that effective vibration mitigation is feasible and economically reasonable.

Example 2: The General Assessment indicates that a proposed commuter rail project has the potential to create vibration impact for a large number of residential buildings adjacent to the alignment. The projections for many of the buildings exceed the impact threshold by less than 5 decibels, which means that more accurate projections may show that vibration levels will be below the impact criterion. Detailed Analysis will refine the impact assessment and help determine whether mitigation is needed.

Example 3: A metro alignment will be close to university research buildings where vibration-sensitive optical instrumentation is used. Vibration from the trains could make it impossible to continue using the building for this type of research. A Detailed Analysis would determine if it is possible to control the vibration from the trains such that sensitive instrumentation will not be affected.

A detailed Vibration Analysis consists of three stages:

1. **Surveying Existing Vibration**: Although knowledge of the existing levels of ground- borne vibration is not usually required for the assessment of vibration impact, there are occasions when a survey of the existing vibration is valuable. These include documenting existing background vibration at sensitive buildings, measuring the vibration levels created by sources such as existing rail lines, and, in some cases, characterizing the general background vibration in the project corridor. Characterizing the existing vibration is discussed in Section 6.1

2. **Prediction of Future Vibration and Vibration Impact**: All of the available tools should be applied to develop the best possible estimates of the potential for vibration impact. Section 6.2 discusses an approach to projecting ground-borne vibration that involves performing tests to characterize vibration propagation at sites where significant impact is probable. Section 6.3 describes the vibration propagation test procedure and Section 6.4 discusses the assessment of vibration impact

3. **Develop Mitigation Measures**: Controlling the impact from ground-borne vibration requires developing cost-effective measures to reduce the vibration levels. The Detailed Analysis helps to select practical vibration control measures that will be effective at the dominant vibration frequencies and compatible with the given transit structure and track support system. Vibration mitigation measures are discussed in Chapter 7.

6.1 CHARACTERISING EXISTING VIBRATIONS CONDITIONS

Environmental vibration is rarely of sufficient magnitude to be perceptible or cause audible ground-borne noise unless there is a specific vibration source close by, such as a rail line. In most cases, perceptible vibration inside a building is caused by equipment or activities within the building itself, such as air-conditioning and ventilation systems, generator sets, if located inside the building, footsteps or doors closing, etc. Because the existing environmental vibration is usually below human perception, a limited vibration survey is sufficient even for a Detailed Analysis. This contrasts with analysis of air borne noise impact where documenting the existing ambient noise level is necessary to assess the overall impact.

Examples of situations where measurement of the ambient vibration is valuable are:

- **Determining existing vibration at sensitive buildings**: Serious vibration impact may occur when there are vibration-sensitive manufacturing, research, or laboratory activities within the screening distances. Careful documentation of the pre-existing vibration provides valuable information on the real sensitivity of the activity to external vibration and gives a reference condition under which vibration is not a problem.

- **Using existing vibration sources to characterize propagation**: Existing vibration sources such as freight trains, industrial activities, quarrying operations, or normal traffic sometimes can be used to characterize vibration propagation. Carefully designed and performed measurements may eliminate the need for more complex propagation tests.

- **Documenting existing levels of general background**: Some measurements of the existing levels of background vibration can be useful simply to document that, as expected, the vibration is below the normal threshold of human perception. Existing vibration in urban and suburban areas is usually due to traffic. If a measurement site has existing vibration approaching the range of human perception (e.g., the maximum vibration velocity levels are greater than about 65 VdB), then this site should be carefully evaluated for the possibility of efficient vibration propagation. Areas with efficient vibration propagation could have vibration problems when the project is built.

- **Documenting vibration from the existing rail lines**: Measurements to document the levels of vibration created by existing rail lines can be important in evaluating the impact of the new vibration source and determining vibration propagation characteristics in the area. If vibration from an existing rail line will be higher than that from the proposed transit trains, there may not be impact even though the normal impact criterion would be exceeded.

Although ground-borne vibration is almost exclusively a problem inside buildings, measurements of existing ambient vibration generally should be performed outdoors. This is due to two important reasons: (1) equipment inside the building may cause more vibration than exterior sources, and (2) the building structure and the resonances of the building can have strong, but difficult to predict, effects on the vibration. However, there are some cases where measurements of indoor vibration are important. Documenting the vibration levels inside a vibration-sensitive building can be particularly important since equipment and activities inside the building sometimes cause vibration greater than that due to external sources such as street traffic or aircraft flying-over. Floor vibration measurements are taken near the centre of a floor span where the vibration amplitudes are the highest.

The goal of most ambient vibration tests is to characterize the root mean square (rms) vertical vibration velocity level at the ground surface. In almost all cases it is sufficient to measure only vertical vibration and ignore the transverse components of the vibration. Although transverse components can transmit significant vibration energy into a building, the vertical component usually has greater amplitudes than transverse vibration. Moreover, vertical vibration is usually transmitted more efficiently into building foundations than transverse vibration.

The manner in which a transducer is mounted can affect the measured levels of ground-borne vibration. However, at the frequencies usually of concern for ground-borne vibration (less than about 200 Hz), straightforward methods of mounting transducers on the ground surface or on pavement are adequate for vertical vibration measurements. Quick-drying epoxy or beeswax is often used to mount transducers to smooth paved surfaces or to metal staked driven into the ground. Rough concrete or rock surfaces require special mountings. One approach is to use a liberal base of epoxy to attach small aluminum blocks to the surface and then mount the transducers on the aluminum blocks.

Selecting sites for an ambient vibration survey requires good common sense. Sites selected to characterize a transit corridor should be distributed along the entire project and should be representative of the types of vibration environments found in the corridor. This would commonly include:

- Measurements in quiet residential areas removed from major traffic arterials to characterize low- ambient vibrations;
- Measurements along major traffic arterials and highways or freeways to characterize high-vibration areas;
- Measurements in any area with vibration-sensitive activities; and
- Measurements at any significant existing source of vibration such as railroad lines.

The transducers should be located near the building setback line for background vibration measurements. Ambient measurements along railroad lines ideally will include: multiple sites; several distances from the rail line at each site; and 4 to 10 train passbys for each test. Rail type and condition strongly affect the vibration levels. Consequently, it is important to inspect the track at each measurement site to locate any switches, bad rail joints, corrugations, or other factors that could be responsible for higher than normal vibration levels

The appropriate methods of characterizing ambient vibration are dependent on the type of information required for the analysis. Following are some examples:

- **Ambient Vibration**: Ambient vibration is usually characterized with a continuous 10 to 30 minutes measurement of vibration. The Leq of the vibration velocity level over the measurement period gives an indication of the average vibration energy. Leq is equivalent to a long averaging time rms level. Specific events can be characterized by the maximum rms level (Lmax) of the event or by performing a statistical analysis of rms levels over the measurement period. An rms averaging time of 1 second should be used for statistical analysis of the vibration level.

- **Specific Events**: Specific events such as train passbys should be characterized by the rms level during the time that the train passes by. If the locomotives/power cars have vibration levels more than 5 dB higher than the passenger or freight cars, a separate rms level for the locomotives/power cars should be obtained. The locomotives/power cars can usually be characterized by the Lmax during the train passby. The rms averaging time or time constant should be 1 second when determining Lmax. Sometimes it is adequate to use Lmax to characterize the train passby, which is simpler to obtain than the rms averaged over the entire train passby.

- **Spectral Analysis**: When the vibration data will be used to characterize vibration propagation or for other special analysis, a spectral analysis of the vibration is required. An example would be if vibration transmission of the ground is suspected of having particular frequency characteristics. For many analyses, 1/3-octave band charts are best for describing vibration behaviour.

Narrowband spectra also can be valuable, particularly for identifying pure tones and designing specific mitigation measures.

It is preferable that ambient vibration be characterized in terms of the root mean square (rms) velocity level, not the peak particle velocity (ppv) as is commonly used to monitor construction vibration as rms velocity is considered more appropriate than ppv for describing human response to building vibration.

6.2 VIBRATION PREDICTION PROCEDURE

Prediction ground-borne vibration associated with a transportation project continues to be a developing field. Because ground-borne vibration is a complex phenomenon that is difficult to model and predict accurately, most projection procedures that have been used for transit projects rely on empirical data. The procedure described in this section is based on site-specific tests of vibration propagation. This procedure is recommended for detailed evaluations of ground-borne vibration. There have been other approaches to a prediction procedure including some that use pure numerical methods. For example, approaches using finite elements are being used to estimate ground-borne vibration from subway tunnels, but most numerical approaches are still in the early stages of development.

6.2.1 Overview of Prediction Procedure: The prediction method described in this section had been developed to allow the use of data collected in one location to accurately predict vibration levels in another site where the geologic conditions may be completely different. The procedure is based on using a special measured function, called transfer mobility. Transfer mobility measured at an existing transit system is used to normalize ground-borne vibration data and remove the effects of geology. The normalized vibration is referred to as the force density. The force density can be combined with transfer mobility measurements at sensitive sites along a new project to develop projections of future ground-borne vibration.

Transfer mobility represents the relationship between a vibration source that excites the ground and the resulting vibration of the ground surface. It is a function of both frequency and distance from the source. The transfer mobility between two points completely defines the composite vibration propagation characteristics between the two points. In most practical cases, receivers are close enough to the train tracks that the vibration cannot be considered to be originating from a single point. The vibration source must be modelled as a line-source. Consequently, the point transfer mobility must be modified to account for a line-source. In the following text, TM_{point} is used to indicate the measured point-source transfer mobility and TM_{line} is used for the line-source transfer mobility derived from TM_{point}.

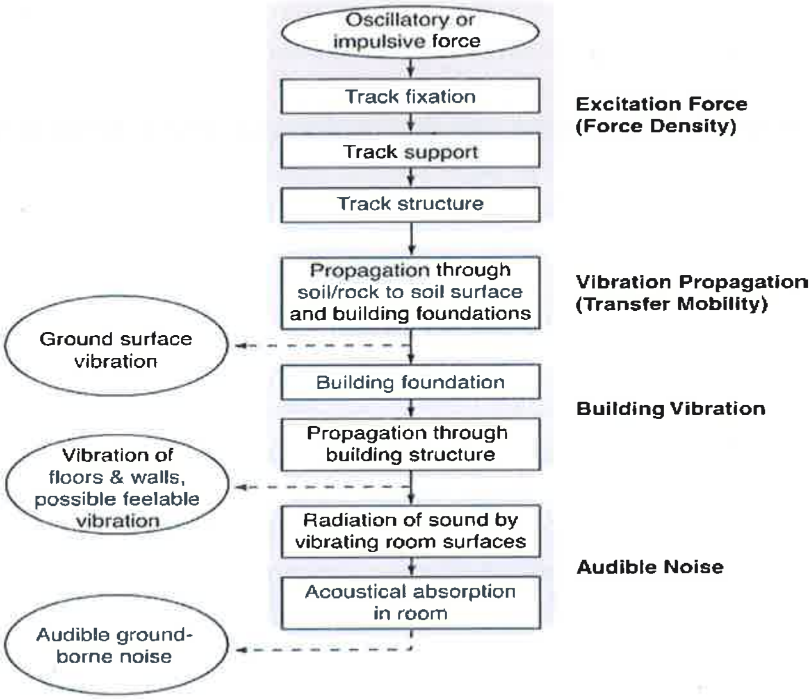

Figure 6.1, Block Diagram of Ground-Borne Vibration and Noise Level

The prediction procedure considers ground-borne vibration to be divided into several basic components as shown schematically in Figure 6.1. The components are:

1. **Excitation Force**: The vibration energy is created by oscillatory and impulsive forces. Steel wheels rolling on smooth steel rails create random oscillatory forces. When a wheel encounters a discontinuity such as a rail joint, an impulsive force is created. The force excites the transit structure, such as tunnel, or the ballast for at-grade track. In the prediction method, the combination of the actual force generated at the wheel/rail interface and the vibration of the transit structure are usually combined into an equivalent force density level. The force density level describes the force that excites the soil/rock surrounding the transit structure.

2. **Vibration Propagation**: The vibration of the transit structure causes vibration waves in the soil that propagate away from the transit structure. The vibration energy can propagate through the soil or rock in a variety of wave forms. All ground vibration includes shear and compression waves. In addition, Rayleigh waves, which propagate along the ground surface, can be a major carrier of vibration energy. The mathematical modelling of vibration is complicated when, as is usually the case, there are soil strata with different elastic properties. As indicated in Figure 6.1, the propagation through the soil/rock is modelled using the transfer mobility, which is usually determined experimentally.

The combination of the force density level and the transfer mobility is used to predict the ground- surface vibration. The projection process, therefore, is simplified in a General Assessment by going directly to generalized estimates of the ground- surface vibration.

3. **Building Vibration**: When the ground vibration excites a building foundation, it sets the building into vibration motion and starts vibration waves propagating throughout the building structure. The interaction between the ground and the foundation causes some reduction in vibration levels. The amount of reduction is dependent on the mass and stiffness of the foundation. The more massive the foundation, the lower the response to ground vibration. As the vibration waves propagate through the building, they can create feelable vibration and can cause annoying rattling of windows and decorative items either hanging or on shelves.

4. **Audible Noise**: In addition to perceptible vibration, the vibration of room surfaces radiates low- frequency sound that may be audible. As indicated in Figure 6.1, the sound level is affected by the amount of acoustical absorption in the receiver room.

A fundamental assumption of the prediction approach outlined here is that the force density, transfer mobility, and the building coupling to the ground are all independent factors. The following equations are the basis for the prediction procedure where all of the quantities are one-third octave band spectral levels in decibels with consistent reference values:

$L_V = L_F + TM_{line} + C_{build}$ $L_A = L_V + K_{rad} + K_{A\text{-}wt}$

Where:

L_V = rms vibration velocity level, L_A = A-weighted sound level,

L_F = force density for a line vibration source such as a train,

TM_{line} = line-source transfer mobility from the tracks to the sensitive site

C_{build} = adjustments to account for ground–building foundation interaction and attenuation of vibration amplitudes as vibration propagates through buildings,

K_{rad} = adjustment to account for conversion from vibration to sound pressure level including accounting for the amount of acoustical absorption inside the room (A value of zero can be used for K_{rad} for typical residential rooms when the decibel reference value for L_V is 25.4 micro mm/sec.),

$K_{A\text{-}wt}$ = A-weighting adjustment at the 1/3-octave band center frequency

All of the quantities given above are functions of frequency. The standard approach to dealing with the frequency dependence is to develop projections on a 1/3-octave band basis using the average values for each 1/3-octave band. The end results of the analysis are the 1/3-octave band spectra of the ground-borne vibration and the ground-borne noise. The spectra are then applied to the vibration criteria for Detailed Analysis. The A-weighted ground-borne noise level can be calculated from the vibration spectrum. This more detailed approach is in contrast to the General Assessment where the overall vibration velocity level and A-weighted sound level are predicted without any consideration of the particular frequency characteristics of the propagation path.

6.2.2 Major Steps in Detailed Analysis:

The major steps in performing a Detailed Analysis are intended to obtain quantities for the equations given above. These are:

1. Develop estimates of the force density. The estimate of force density can be based on previous measurements or a special test program can be designed to measure the force density at an existing facility. If no suitable measurements are available, testing should be done at a transit facility with equipment similar to the planned vehicles. Adjustments for factors such as train speed, track support system, and vehicle suspension may be needed to match the force density to the conditions at a specific site. Some appropriate adjustments can be found in the report "State-of-the-Art Review: Prediction and Control of Ground-Borne Noise and Vibration from Rail Transit Trains (TCRP Report no. 23 by Transport Research Board, National Research Council, USA)."

2. Measure the point-source transfer mobility at representative sites. The transfer mobility is a function of both frequency and distance from the source. Point-source transfer mobility is used for sources with short lengths, such as single vehicles or columns supporting elevated structures.

3. Use numerical integration to estimate a line-source transfer mobility from the point-source transfer mobilities. Line-source transfer mobility is applicable to long sources like trains.

4. Combine force density and line-source transfer mobility to project ground-surface vibration.

5. Add adjustment factors to estimate the building response to the ground-surface vibration and to estimate the A-weighted sound level inside buildings.

The two key elements of the transfer mobility procedure are a measured force function that represents the vibration energy put into the ground and a measured transfer mobility that characterizes the propagation of the vibration from the source to the receiver. The unit of force density is force divided by square root of train length, represented here in decibels relative to 1 $lb/(ft)^{1/2}$ (or 0.82 $Kgf/m^{1/2}$). The force density represents an incoherent line of vibration force equal to the length of transit trains. The process of estimating force density from train vibration and transfer mobility tests is discussed in Section 6.3. Figure 6.2 shows some track-bed force densities that have been developed from measurements of vibration from heavy and light rail transit vehicles. This figure provides a comparison of the vibration forces from heavy commuter trains and light rail transit vehicles with different types of primary suspensions illustrating the range of vibration forces commonly experienced in a transit system. A force density of a vehicle includes the characteristics of its track support system at the measurement site. Adjustments must be made to the force density to account for differences between the facility where the force density was measured and the new system being analysed.

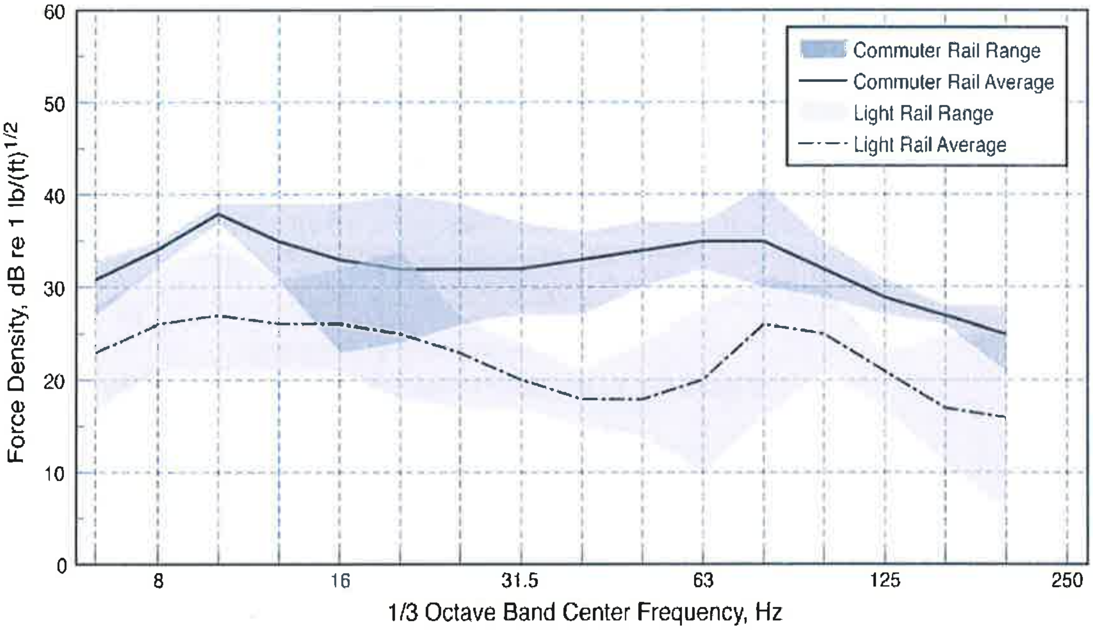

Figure 6.2, Typical Force Density for Rail Transit Vehicles, 64.3 kmph

The key elements of the vibration prediction procedure are implementation of field tests to measure the transfer mobility and the subsequent use of transfer mobility to characterize vibration propagation. The process of measuring transfer mobility involves impacting the ground and measuring the resulting vibration pulse at various distances from the impact. Standard signal-processing techniques are used to determine the transfer function, or frequency response function, between the exciting force and the resultant ground-surface vibration. Numerical regression methods are used to combine a number of two- point transfer functions into a smooth point-source transfer mobility that represents the average vibration propagation characteristics of a site as a function of both distance from the source and frequency. The transfer mobility is usually expressed in terms of a group of 1/3-octave band transfer mobilities. This processing is performed after transferring the data to a computer. Figure 6.3 shows the point-source transfer mobilities from a series of tests at the Transportation Technology Center in Pueblo, Colorado, USA.

Once the point-source transfer mobility has been defined, the line-source transfer mobility can be calculated using numerical integration techniques. For detailed description of the process, Transportation Research Board paper, Record 1143, August 1998 can be referred to. Figure 6.4 shows the line-source transfer mobilities that were derived from the point-source transfer mobilities shown in Figure 6.3. The line-source transfer mobilities are used to normalize measured vibration velocity levels from train passbys and to obtain force density

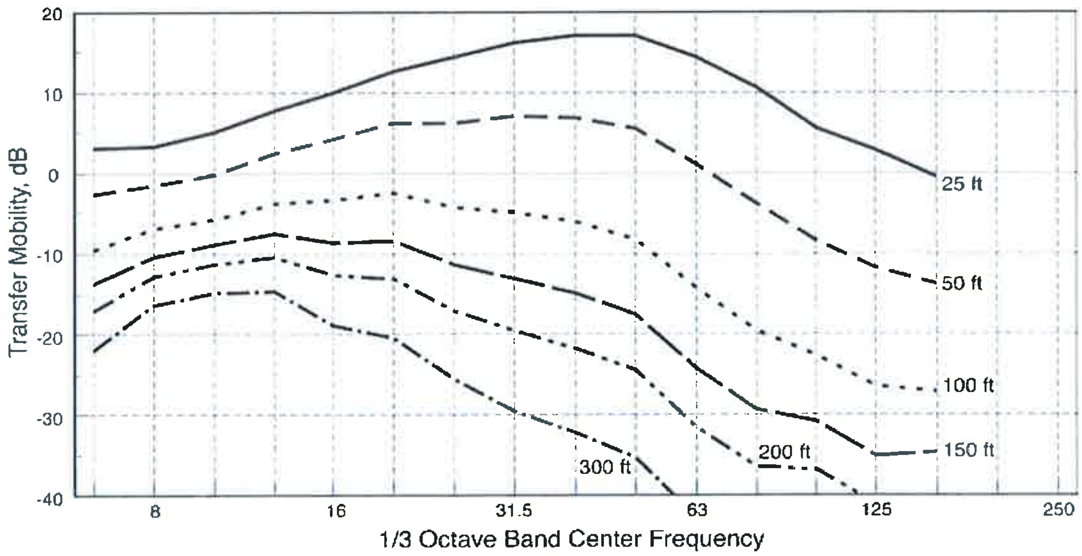

Figure 6.3, Example of Point Source Transfer Mobility

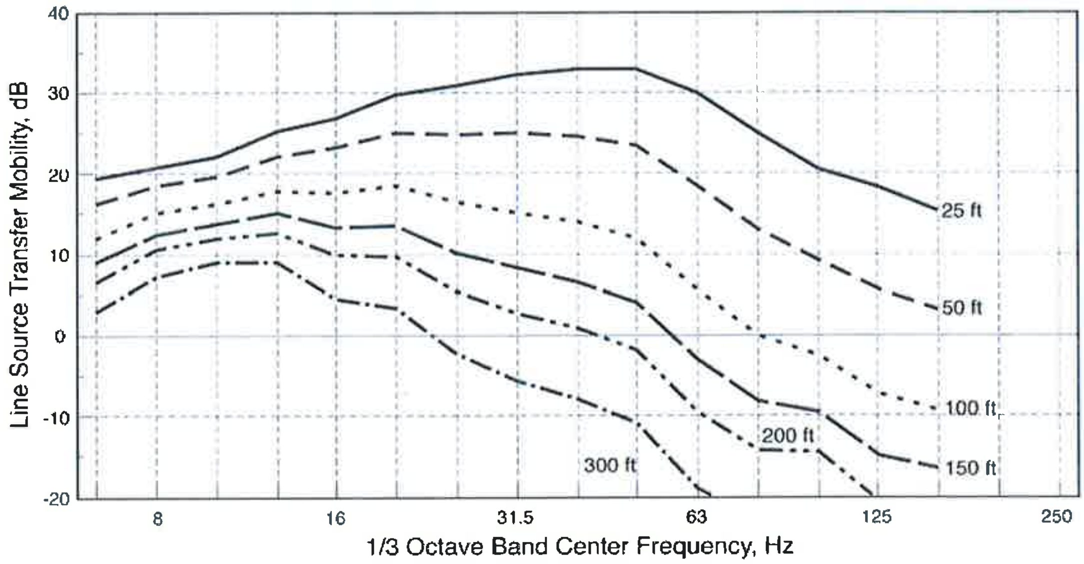

Figure 6.4, Examples of Line Source Transfer Mobility

The propagation of vibration from the building foundation to the receiver room is a very complex problem dependent on the specific design of the building. Detailed evaluation of the vibration propagation would require extensive use of numerical procedures such as the finite element method. Such a detailed evaluation is generally not practical for individual buildings considered in this document. The propagation of vibration through a building and the radiation of sound by vibrating building surfaces is consequently estimated using simple empirical or theoretical models. The recommended procedures are outlined in the Handbook of Urban Rail Noise and Vibration Control, Report UMTA-MA-06-099-82-2, Feb., 1982, US Transportation Systems Center. The approach consists of adding the following adjustments to the 1/3-octave band spectrum of the projected ground-surface vibration:

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1. **Building Response or Coupling Loss**: This represents the change in the incident ground-surface vibration due to the presence of the building foundation. The adjustments as referred to in the Handbook, are shown in Figure 6.5. Note that the correction is zero when estimating basement floor vibration or vibration of at-grade slabs. Measured values may be used in place of these generic adjustments.
2. **Transmission through the building:** The vibration amplitude typically decreases as the vibration energy propagates from the foundation through the remainder of the building. The normal assumption is that vibration attenuates by 1 to 2 dB for each floor.
3. **Floor Resonances:** Vibration amplitudes will be amplified because of resonances of the floor/ceiling systems. For a typical wood-frame residential structure, the fundamental resonance is usually in the 15- to 20-Hz range. Reinforced-concrete slab floors in modern buildings will have fundamental resonance frequencies in the 20- to 30- Hz range. An amplification resulting in a gain of approximately 6 dB should be used in the frequency range of the fundamental resonance.

The projected floor vibration is used to estimate the levels of ground-borne noise. The primary factors affecting noise level are the average vibration level of the room surfaces and the amount of acoustical absorption within the room. As discussed above, the radiation adjustment is zero for typical rooms, which gives:

$$L_A \approx L_v + K_{A-wt}$$

Where LA is the A-weighted sound level in a 1/3-octave band, Lv is the vibration velocity level in that band, and KA-wt is the A-weighting adjustment at the center frequency of the 1/3-octave band. The A-weighted levels in the 1/3-octave bands are then combined to give the overall A-weighted sound level.

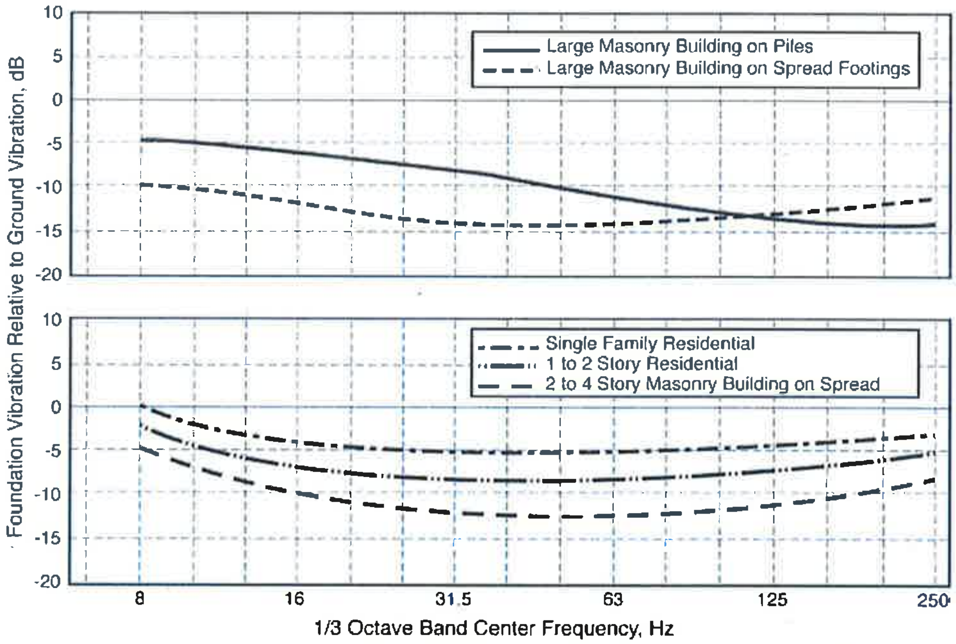

Figure 6.5, Foundation Response for Various Types of Buildings

6.3 MEASURING TRANSFER MOBILITY AND FORCE DENSITY

The test procedure to measure transfer mobility basically consists of dropping a heavy weight on the ground and measuring the force into the ground and the response at several distances from the impact. The goal of the test is to create vibration pulses that travel from the source to the receiver using the same path that will be taken by the transit system vibration. The transfer mobility expresses the relationship between the input force and the ground-surface vibration.

Figure 6.6 illustrates the field procedure for at-grade and subway testing of transfer mobility. A weight is dropped from a distance of about 1 meter onto a force transducer. The responses of the force and vibration transducers are recorded on a multichannel tape recorder for later analysis in the laboratory. An alternative approach is to set up the analysis equipment in the field and capture the signals directly. This complicates the field testing but eliminates the laboratory analysis of tape-recorded data.

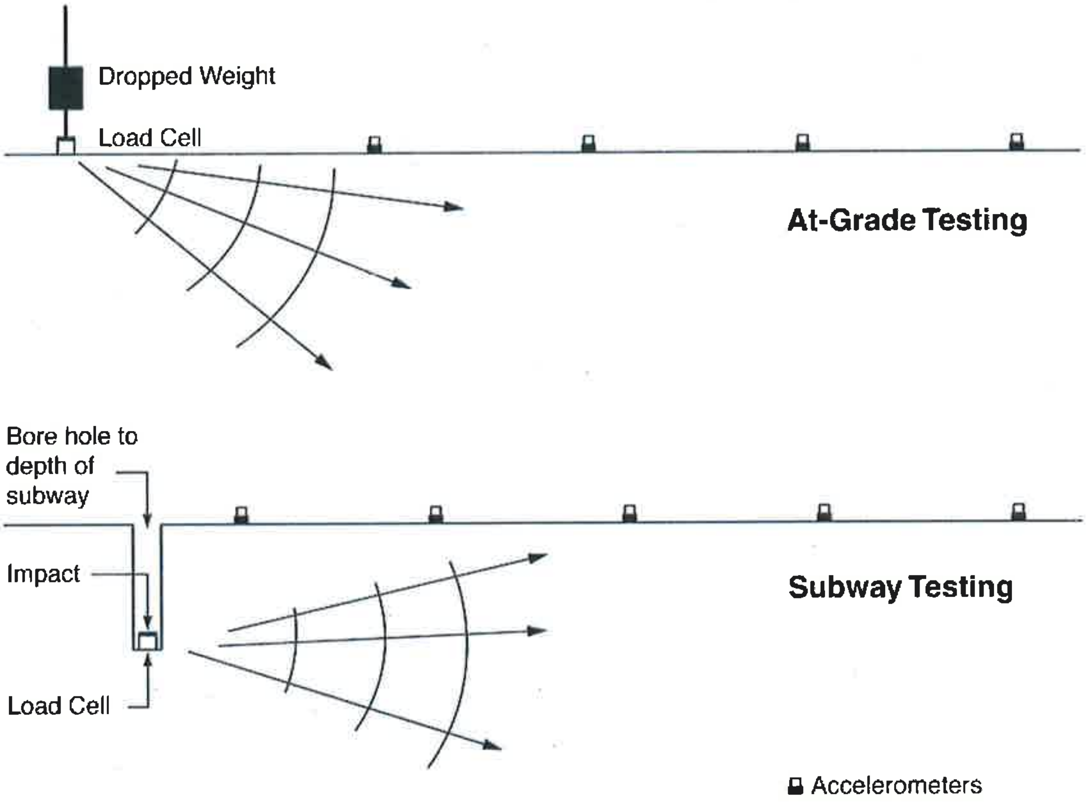

Figure 6.6 Test Configuration for Measuring Transfer Mobility

When the procedure is applied to subways/tunnels, the force must be located at the approximate depth of the tunnel. This is done by drilling a bore hole and locating the force transducer at the bottom of the hole. The tests are usually performed at the same time that the bore holes are drilled. This allows using the soil-sampling equipment on the drill rig for the transfer mobility testing. The force transducer is attached to the bottom of the drill string and lowered to the bottom of the hole. A standard soil sampling hammer, which is usually a 63.5 Kg weight dropped by 46 cms onto a collar attached to the drill string, is used to excite the ground. The force transducer must be capable of operating under water if the water table is near the surface or a slurry drilling process is used.

6.3.1 Instrumentation

Performing a transfer mobility test requires specialized equipment. Most of the equipment is readily available from commercial sources. A load cell can be used as the force transducer. The force transducer should be capable of impact loads of 2.2 to 4.4 ton (5,000-10,000 lb). For borehole testing, the load cell must be hermetically sealed and capable of being used at the bottom of a 9 to 30 meters deep hole partially filled with water. Typical instrumentation for the field-testing and laboratory analysis of transfer mobility is shown in Figure 6.7. Either accelerometers or geophones can be used as the vibration transducers. The requirement is that the that the transducers with the associated amplifiers be capable of accurately measuring levels of 0.0025 mm/sec at 40 Hz and have a flat frequency response from 6 Hz to 400 Hz. Data must be acquired (either with digital audio tape or an alternative digital acquisition system) with a flat frequency response over the range of 6 to 400 Hz.

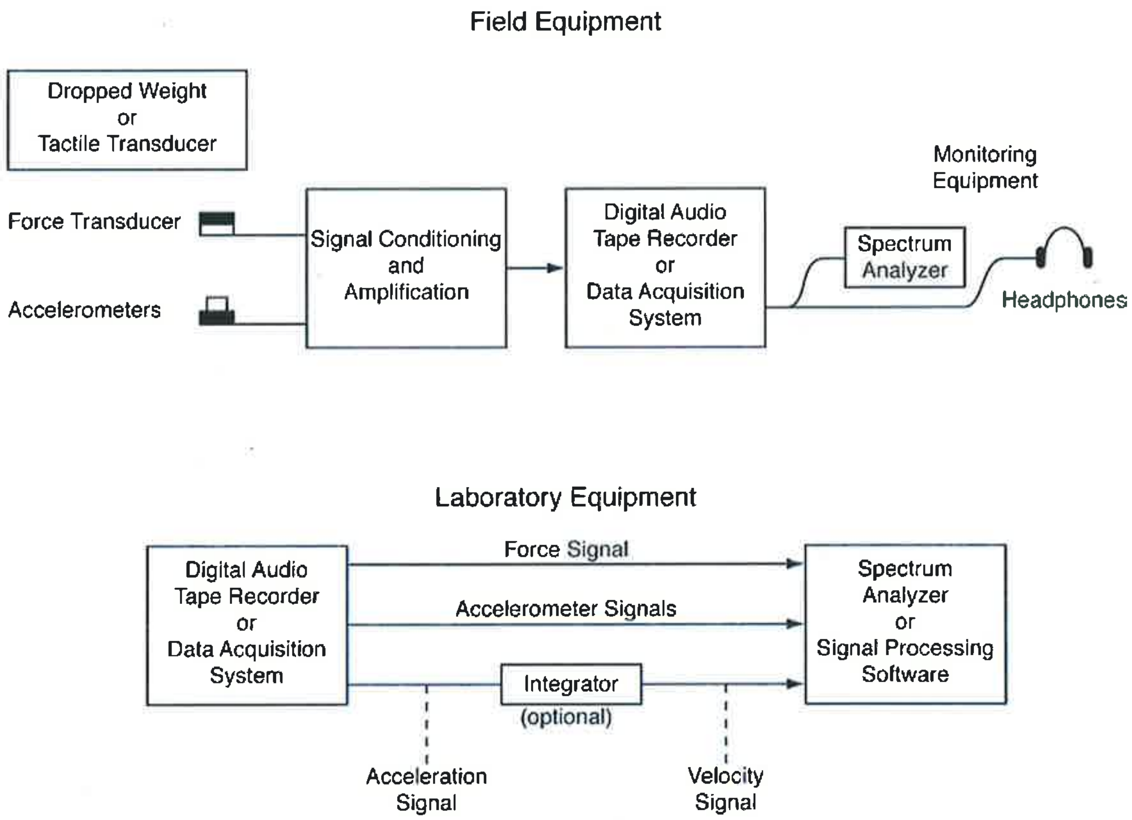

Figure 6.7, Equipment Required for Field Testing and Laboratory Analysis

A narrowband spectrum analyser or signal-processing software can be used to calculate the transfer function and coherence between the force and vibration data. The analyser must be capable of capturing impulses from at least two channels to calculate the frequency spectrum of the transfer function between the force and vibration channels. All transfer functions should include the average of at least 20 impulses. The averaging of the impulses will provide significant signal enhancement, which is usually required to accurately characterize the transfer function. Signal enhancement is particularly important when the vibration transducer is more than 30 meters from the impact.

Transfer mobility may also be measured using other methods. One such method involves producing maximum-length sequence (MLS) force impulses with a tactile transducer. Signal-processing software is then used to calculate the transfer function from the MLS forces and measured vibrations. The MLS measurement method uses a pseudo-random binary sequence as the signal and has the advantage of increasing the signal-to-noise ratio of the measurement.

The laboratory equipment in Figure 6.7 shows using either a spectrum analyser or signal-processing software to calculate the transfer function. Specialized multi- channel spectrum analysers have built-in capabilities for computing transfer functions. The use of a spectrum analyser has the advantage of being computationally efficient. On the other hand, signal-processing software can offer more flexibility in analysing data signals and allows the use of different digital signal processing methods such as the MLS. Typical measurement programs involve acquisition of data in the field and later processing of the information in a laboratory. However, recent advances in instrumentation and signal-processing software allow data to be collected and analysed while in the field.

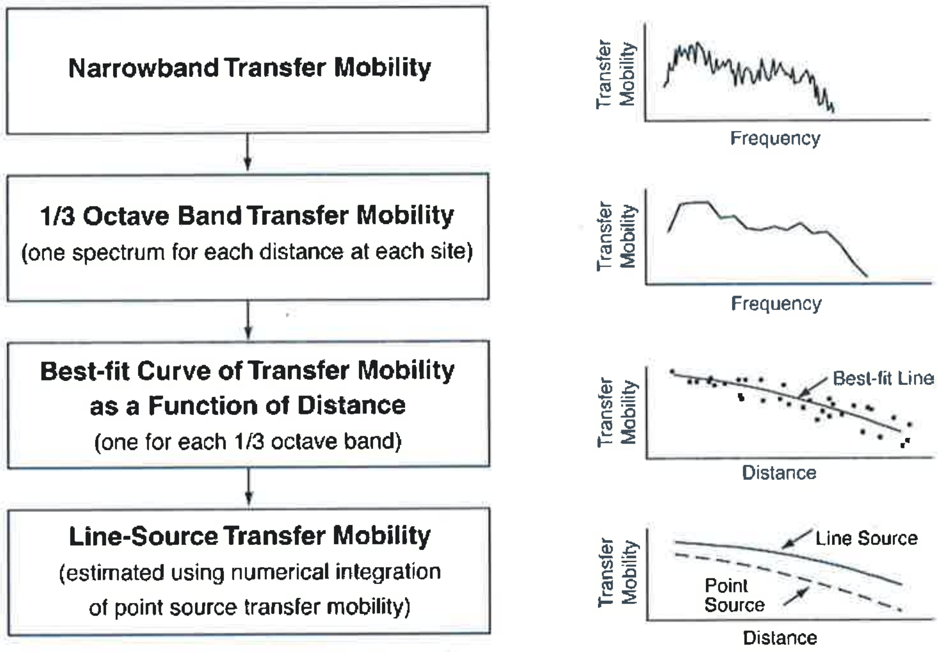

Figure 6.8, Analysis of Transfer Mobility

6.3.2 Analysis of Transfer Mobility Data

Two different approaches have been used to develop estimates of line-source transfer mobility. The first consists of using lines of transducers and the second consists of a line of impact positions. The steps to develop line-source transfer mobility curves from tests using one or more lines of transducers are shown in Figure 6.8. The procedure starts with the narrowband transfer function between source and receiver at each measurement position. There should be a minimum of four distances in any test line. Because of the possibility of local variations in propagation characteristics, if at all possible, two or more lines should be used to characterize a site. A total of 10 to 20 transducer positions are often used to characterize a site.

The first step in the analysis procedure is to calculate the equivalent 1/3-octave band transfer functions. This reduces each spectrum to 15 numbers. As shown in Figure 6.8, the 1/3-octave band spectrum is much smoother than the narrowband spectrum. The next step is to calculate a best-fit curve of transfer mobility as a function of distance for each 1/3-octave band. When analysing a specific site, the best-fit curve will be based on 10 to 20 points. Up to several hundred points could be used to determine average best-fit curves for a number of sites.
The 1/3-octave band best-fit curves can be directly applied to point vibration sources. Buses can usually be considered to be point-sources, as can columns supporting elevated structures. However, for a line vibration source such as a train, numerical integration must be used to calculate an equivalent line-source transfer mobility.

The second procedure for estimating line-source transfer mobility, shown schematically in Figure 6.9, is best for detailed assessment of specific vibration paths or specific buildings. The vibration transducers are located at specific points of interest and a line of impacts is used. For example, a 55 meter train might be represented by a line of 11 impact positions along the track centerline at 5-meter intervals. It is possible to sum the point-source results using Simpson's rule for numerical integration to directly calculate line-source transfer mobility. This is a considerably more direct approach than is possible with lines of vibration transducers.

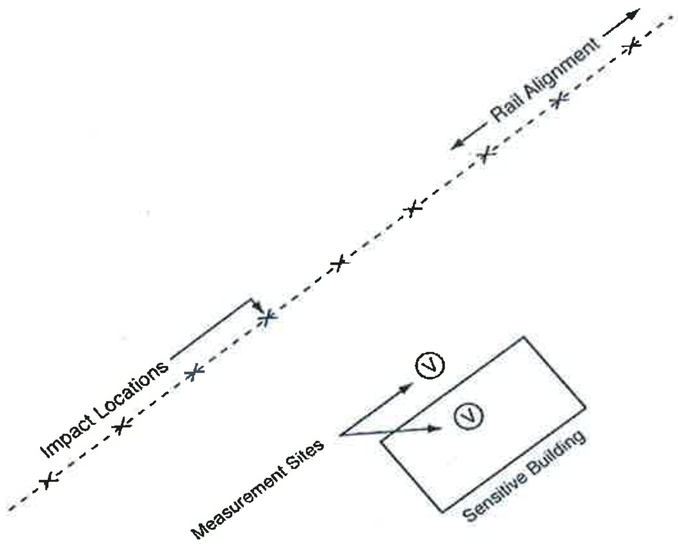

Figure 6.9, Schematic of Transfer Mobility Measurements Using a Line of Impacts

6.3.3 Deriving Force Density

Force Density is not a quantity that can be measured directly; it must be inferred from measurements of transfer mobility and train vibration at the same site. For deriving force density, the best results are achieved by deriving line-source transfer mobility from a line of impacts. The force density for each 1/3- octave band is then simply:

$LF = Lv - TM_{line}$

Where LF is the force density, Lv is measured train ground-borne vibration, and TM_{line} is the line-source transfer mobility. The standard approach is to use the average force density from measurements at three or more positions.

6.4 ASSESSMENT OF VIBRATION IMPACT

The goals of the vibration assessment are to know all sensitive land uses that may be adversely impacted by the ground-borne vibration and noise from the proposed project and to determine the mitigation measures that will be required to eliminate or minimize the impact. This requires projecting the levels of ground-borne vibration and noise, comparing the projections with the impact criteria, and developing a list of suitable mitigation measures. Note that the General Assessment is incorporated as an intermediate step in the impact assessment because of its relative simplicity and potential to narrow the areas where Detailed Analysis needs to be done.

The assessment of vibrations impact should proceed taking the following steps:

1. Screen the entire proposed transit alignment to identify areas where there is the potential of impact from ground-borne vibration. The vibration screening procedure is described in Chapter 4. If no sensitive land uses are within the screening distances, it is not necessary to perform any further assessment of ground-borne vibration.

2. Define the curves of ground-surface vibration level as a function of distance that can be used with the General Assessment. Usually this will mean selecting the appropriate curve from Chapter 5 for the proposed transit mode. For less common transit modes, it may be necessary to make measurements at an existing facility.

3. Use the General Assessment procedure to estimate vibration levels for specific buildings or groups of buildings. The projected levels are compared with the impact criteria for General Vibration Assessment (Tables 3.9 and 3.10) to determine whether vibration impact is likely. The goal of this step is to develop a reasonably accurate list of the buildings that will experience ground-borne vibration or noise levels that exceed the criteria. Applying the impact criteria for the General Assessment will result in a conservative assessment of the impact. That is, it is possible that some buildings that are identified as impacted may not be impacted under a more detailed analysis. However, at this stage it is better to include some buildings that may not be impacted than to exclude some buildings that are likely to be impacted. In locations where the General Assessment indicates impact, the more refined techniques of Detailed Analysis would be employed.

4. In some cases it will be necessary to perform a vibration survey to characterize existing ambient vibration. As discussed in Section 6.1, although knowledge of the existing ambient vibration is not generally required to evaluate vibration impact, there are times when a survey of existing conditions is valuable. One common example is when a rail transit project will be located in an existing railroad right-of-way shared by freight trains. Chapter 3 includes some guidelines on how to account for existing vibration that is higher than the impact limit for the project vibration.

5. For areas where the General Assessment impact criteria are exceeded, review potential mitigation measures and assemble a list of feasible approaches to vibration control. To be feasible, the measure, or combination of measures, must be capable of providing a significant reduction of the vibration levels, at least 5 dB, while being reasonable from the standpoint of the added cost. The impact assessment and review of mitigation measures are preliminary at this point because vibration control is frequency-dependent, and specific recommendations of vibration control measures can be made only after evaluating the frequency characteristics of the vibration.

6. Use the Detailed Vibration Analysis to refine the impact assessment and to develop detailed vibration mitigation measures where needed. It is usually necessary to project vibration spectra at buildings which will be affected at levels higher than the impact thresholds. This type of assessment is normally performed as part of final design rather than during the environmental impact assessment stage. Because a Detailed Analysis is more accurate than a General Assessment, there will be times that the Detailed Analysis will show that the ground-borne vibration and noise levels will be below the applicable criteria and that mitigation is not required. If the projected levels are still above the limits, the spectra provided by the Detailed Analysis will be needed to evaluate vibration control approaches.

Chapter-7

Mitigation Measures

7.1 This chapter discusses Mitigation Measures both for radiated (air-borne) noise or simply categorised as 'Noise' and for ground borne vibration and noise. Though there may be common solutions, the metro planners/operators normally approach two types of issues separately as the basics mechanism of propagation and impact criteria of the two are different as discussed in preceding chapters. Section 7.1 deals with Mitigation Measures for radiated noise, and section 7.2 for Mitigation Measures for ground borne vibration and noise.

7.2 MITIGATION MEASURES FOR NOISE (RADIATED or AIR-BORNE)

Where the noise impact assessment shows either Severe Impact or Moderate Impact, this section provides guidance on considering and implementing noise reduction measures. In general, mitigation options are chosen from those suggested in the section, and then portions of the project noise are recomputed and reassessed to account for the mitigation expected to be provided by the measure planned. This allows an accurate prediction of the level of noise reduction. Since cost considerations often play into decisions before committing to a given mitigation measure, the content of this document should be used more as a guideline than a stipulation and final decision be arrived at after a reasonable cost cum benefit consideration from a given mitigation measure is arrived at.

Mitigation of noise impact from transit projects may involve treatments at the three fundamental components of the noise problem: (1) at the noise source, (2) along the source-to-receiver propagation path or (3) at the receiver. Generally, the transit/metro bodies have authority to treat the source and some elements of the propagation path, but may have little or no authority to modify anything at the receiver end.

A list of practical noise mitigation measures that should be considered by project owner/concessionaire is summarized in Table 7.1 followed with discussion. This table is organized according to whether the treatment applies to the source, path or receiver, and includes a rough estimate of the acoustical effectiveness of each treatment.

7.2.1 Source Treatments

Vehicle Noise Specifications

Among the most effective noise mitigation treatments is noise control at the outset, during the specification and design of the transit vehicle. Such source treatments apply to all transit modes. By developing and enforcing stringent but achievable noise specifications, the transit owner takes a major step in controlling noise everywhere on the system. It is important to ensure that the noise levels quoted in the specifications are achievable with the application of best available technology during the development of the vehicle, and reasonable in light of the noise reduction benefits and costs.

Effective enforcement may include significant penalties for non-compliance with the specifications. The noise mitigation achieved by source treatment depends on the quality of installation and maintenance. Delivery of rolling stock that do not meet given noise specification, invariably result in causing complaints from the public and requiring additional noise mitigation measures to be applied.

Table 7.1 Transit Noise Mitigation Measures

Application	Mitigation Measure		Effectiveness
SOURCE	Stringent Vehicle & Equipment Noise Specifications		Varied
	Operational Restrictions		Varied
	Resilient or Damped Wheels*	For Rolling Noise on Tangent Track:	2 dB
		For Wheel Squeal on Curved Track:	10-20 dB
	Vehicle Skirts *		6-10 dB
	Undercar Absorption *		5 dB
	Spin-slide control (prevents flats) *		**
	Wheel Truing (eliminates wheel flats) *		**
	Rail Grinding (eliminates corrugations) *		**
	Turn Radii greater than 305 m *		(Avoids Squeal)
	Rail Lubrication on Sharp Curves *		(Reduces Squeal)
	Movable-Point Frogs (reduce rail gaps at crossovers) *		(Reduces Impact Noise)
	Engine Compartment Treatments (Buses)		6-10 dB
PATH	Sound Barriers close to Vehicles		6-15 dB
	Sound Barriers at ROW Line		3-10 dB
	Alteration of Horiz. & Vert. Alignments		Varied
	Acquisition of Buffer Zones		Varied
	Ballast on At-Grade Guideway *		3 dB
	Ballast on Aerial Guideway *		5 dB
	Resilient Track Support on Aerial Guideway		Varied
RECEIVER	Acquisition of Property Rights for Construction of Sound Barriers		5-10 dB
	Building Noise Insulation		5-20 dB

*Applies to rail projects only

**These mitigation measures work to maintain a rail system in its as-new condition. Without incorporating them into the system, noise levels could increase up to 10 dB.

Wheel Treatments

A major source of noise from steel-wheel/steel-rail systems is the wheel/rail interaction which has three components: roar, impact and squeal. Roar is the rolling noise caused by small-scale roughness on the wheel tread and rail running surface. Impacts are caused by discontinuities in the running surface of the rail or by a flat spot on the wheels. Squeal occurs when a steel-wheel tread or its flange rubs across the rail, setting up resonant vibrations in the wheel which cause it to radiate a screeching sound. Various wheel designs and other mitigation measures exist to reduce the noise from each of these three mechanisms discussed as follows:

- **Resilient Wheels** serve to reduce rolling noise, but only slightly. A typical reduction is 2 decibels on tangent track. This treatment is more effective in eliminating wheel squeal on tight turns; reductions of 10 to 20 decibels for high- frequency squeal noise are typical.

- **Damped Wheels,** like resilient wheels, serve to reduce rolling noise with typical reduction being 2 dB on tangent track. This treatment involves attaching vibration absorbers to standard steel wheels. Damping is effective in eliminating wheel squeal on tight turns; reductions of 5 to 15 decibels for high-frequency squeal noise are typical.
- **Spin-slide Control System,** similar to anti-locking brake systems (ABS) on automobiles, reduces the incidence of wheel flats, a major contributor of impact noise. Trains with smooth wheel treads can be up to 20 decibels quieter than those with wheel flats. To be effective, the anti-locking feature should be in operation during all braking phases, including emergency braking. Wheel flats are more likely to occur during emergency braking than during dynamic braking. It is desirable if the cost of slip-slide control may be incorporated in the new vehicle costs at planning stage itself.

- **Maintenance of wheels** by truing eliminates wheel flats from the treads and restores the wheel profile. As discussed above, wheel flats are a major source of impact noise. A good maintenance program includes the installation of equipment to detect and correct wheel flats on a continuing basis and can be far more economical mitigation measure than many.

Vehicle Treatments

Vehicle noise mitigation measures are applied to the various mechanical systems associated with propulsion, ventilation and passenger comfort.

- **Propulsion Systems** of transit vehicles include diesel engines, electric motors and diesel-electric combinations. Noise from the propulsion system depends on the type of unit and how much noise mitigation is built into the design. Control of noise from engine casings may require shielding the engine by body panels without louvers, dictating other means of cooling and ventilation.

- **Ventilation requirements** for vehicle systems are related to the noise generated by a vehicle. Fan noise often remains a major noise source after other mitigation measures have been instituted because of the need to have direct access to cooling air. This applies to heat exchangers for electric traction motors, diesel engines and air-conditioning systems. Fan-quieting can be accomplished by installation of one of several new designs of quiet, efficient fans. Forced-air cooling on electric traction motors can be quieter than self-cooled motors at operating speeds. Placement of fans on the vehicle can make a significant difference in the noise radiated to the wayside or to the people on station platforms.

- The **Vehicle body design** can provide shielding and absorption of the noise generated by the vehicle components. Acoustical absorption under the car has been demonstrated to provide up to 5 decibels of mitigation for wheel/rail noise and propulsion-system noise on rapid transit trains. Similarly, vehicle skirts over the wheels can provide more than 5 decibels of mitigation. By carrying their own noise barriers, vehicles with these features can provide cost-effective noise reduction.

Guide-way Surface (Rail top)

The smoothness of the running surface is critical in the mitigation of noise from a moving vehicle. Smooth rail running surfaces for rail systems are required and to achieve this rail grinding and achieving target rail profile should be resorted to. This measure can reduce noise levels by up to 10 decibels.

Operational Restrictions

Two changes in operations that can mitigate noise are the lowering of speed and the reduction of night time (10 pm to 7 am) operations. Because noise from most transit vehicles depends on speed, a reduction of speed results in lower noise levels. The effect can be considerable. For example, the speed dependency of steel-wheel/steel-rail systems for Leq and Ldn results in a 6 dB reduction for a halving of the speed. Complete elimination of night time operations has a strong effect on reducing the Ldn as night time noise is increased by 10 decibels when calculating Ldn. Restrictions on operations, however, are usually not feasible because of service demands. Early morning idling, however, can be curtailed to the minimum necessary which can have a measurable effect on Ldn.

7.2.2 Path Treatments

Sound Barriers

Sound barriers are effective in mitigating noise when they break the line of sight between source and receiver. The mechanism of sound shielding is described in Chapter 1. The necessary height of a barrier depends on such factors as the source height and the distance from the source to the barrier. For example, if a barrier is located very close to a metro train, it need only be about one meter above the top of rail to be effective. Barriers close to vehicles can provide noise reductions of 6 to 10 decibels. For barriers further away, such as on the land boundary or for trains on the far track, the height must be increased to provide equivalent effectiveness. Otherwise, the effectiveness can drop to 5 decibels or less, even if the barrier breaks the line-of-sight. Where the barrier is very close to the transit vehicle or where the vehicles travel between sets of parallel barriers, barrier effectiveness can be increased by as much as 5 decibels by applying sound-absorbing material to the inner surface of the barrier.

Similarly, the length of the barrier wall is important to its effectiveness. The barrier must be long enough to screen out a moving train along most of its visible path. This is necessary so that train noise from beyond the ends of the barrier will not severely compromise noise-barrier performance at sensitive locations.

Noise barriers can be made of any outdoor weather-resistant solid material that meets a minimum sound transmission loss requirement. The sound requirements are not particularly strict; they can be met by many commonly available materials, such as steel sheet, plywood, composite recycled material, reasonable thickness of concrete, etc. Achieving the maximum possible noise reduction requires careful sealing of gaps between barrier panels and between the barrier and the ground or elevated guide-way deck.

Locating a transit alignment in cutting can accomplish the same result as installation of a noise barrier at-grade or on viaduct structure. The walls of the cutting serve the same function as barrier walls in breaking the line-of-sight between source and receiver.

Noise Buffers

Because noise levels attenuate with distance, one noise mitigation measure is to increase the distance between noise sources and the closest sensitive receivers. This can be accomplished by locating alignments away from sensitive sites. Acquisition of land or purchasing easements for noise buffer zones is an option that may be considered if impacts due to the project are severe enough.

Ground Absorption

Propagation of noise over ground is affected by whether the ground surface is absorptive or reflective. Guide-ways for rail systems can be either reflective or absorptive, depending on whether they are concreted or ballasted. Ballast on a guide-way can reduce train noise 3 decibels at-grade and up to 5 decibels on aerial (viaduct) structure.

Track Support Resilience

The resilience built in the track though support or fastening system plays a crucial role in mitigating noise. A resilient fastening system may even be of more help in reducing ground borne vibrations which is discussed in next section. Trade offer high-resilience fastening designs holding rail through web, controlling noise as well as ground-borne vibrations. As these types of systems are costlier than conventional ones, their need should be examined after carrying detailed impact assessment.

7.2.3 Receiver Treatments

Sound Barriers

In certain cases it may be possible to acquire limited property rights for the construction of sound barriers at receiver. As discussed above, barriers need to break the line-of-sight between the noise source and the receiver to be effective and are most effective when they are closest to either the source or the receiver. For computational procedures for estimating barrier effectiveness, FTA manual can be referred to.

Building Insulation

In cases where sound barriers are not feasible, such as multi-story buildings, buildings very close to the rights-of-way, or grade crossings, the only practical noise mitigation measure may be to provide sound insulation for the buildings. Effective treatments include caulking and sealing gaps in the building façade, and installation of new doors and windows that are specially designed to meet acoustical transmission-loss requirements. Exterior doors facing the noise source should be replaced with well gasketed solid-core wood doors. Acoustical windows are usually made of multiple layers of glass with air spaces between to provide noise reduction. These treatments are beneficial for heat insulation as well as for sound insulation.

Additional building sound insulation, if needed, can be provided by sealing vents and ventilation openings and relocating them to a side of the building away from the noise source. In order to be considered cost-effective, a treatment should provide a minimum of 5 dBA reduction in the interior of the building and provide an interior noise level of 65 dBA or less from transit sources.

7.3 MITIGATION MEASURES FOR VIBRATION (Ground borne Vibration & Noise)

The purpose of vibration mitigation is to minimize the adverse effects that the project ground-borne vibration will have on sensitive land uses. Because ground-borne vibration is not as common a problem as radiated (air-borne) noise, the mitigation approaches have not been as well defined. In some cases it has been necessary to develop innovative approaches to control the impact such as floating-slab system.

The importance of adequate wheel and rail maintenance in controlling levels of ground-borne vibration cannot be overemphasized. It is very important to note that problems with rough wheels or rails can increase vibration levels by as much as 20 dB in extreme cases, negating the effects of even the most effective vibration control measures. It is rare that practical vibration control measures will provide more than 15 to 20 dB attenuation. When there are ground-borne vibration problems with existing transit equipment, the best vibration control measure often is to implement new or improved maintenance procedures. Grinding rough or corrugated rail and wheel turning to eliminate wheel flats and restore the wheel contour may provide more vibration reduction than would be obtainable from completely replacing the existing track system with the most proven method of floating slabs.

Given that the track and vehicles are in good condition, the options for further reductions in the vibration levels fit into one of seven categories: (1) maintenance procedures, (2) location and design of special track work, (3) vehicle modifications, (4) changes in the track support system, (5) building modifications, (6) adjustments to the vibration transmission path, and (7) operational changes.

Vibration reduction measures incur additional costs to a system. In case measures are being taken for mitigation for noise as discussed in section 7.2, it's favourable impact on vibration attenuation should also be assessed to assess if there is any further need.

7.3.1 Maintenance

As discussed in the preceding sections, effective maintenance programs are essential for controlling ground-borne vibration. When the wheel and rail surfaces are allowed to degrade the vibration levels can increase by as much as 20 dB compared to a new or well-maintained system. Some maintenance procedures that are particularly effective at avoiding increases in ground-borne vibration are:

- Rail grinding on a regular basis. Rail grinding is particularly important for rail that develops corrugations or other surface defects. It has been established through practice on advance railway systems that periodic rail grinding actually results in a net savings per year on wheel and rail wear. The regime of rail grinding can be contracted out or developed departmentally.

- Wheel turning or wheel truing to re-contour the wheel, provides a smooth running surface and remove wheel flats. The most dramatic vibration reduction results from removing wheel flats. However, significant improvements also can be observed simply from smoothing the running surface.

- Implement vehicle reconditioning programs, particularly when components such as suspension system, brakes, wheels, and slip-slide detectors will be involved. The regular regime of reconditioning helps not only mitigation of vibration but also in lower resultant defect generation.

- Install wheel flat detector system to identify vehicles which are most in need of wheel truing. These systems are becoming more common on conventional railway systems and intercity passenger systems, but are relatively rare on transit/metro systems. Detection and isolation of defective vehicle also helps in higher asset reliability and safety besides vibration mitigation.

7.3.2 Planning & Relocating Track Joints, Turnouts

A large percentage of vibration impact from a new transit facility is often caused by wheel impacts at the special location of track joints, turnouts and crossovers. When feasible, the most effective vibration control measure is to relocate the special track work to a less vibration-sensitive area. Sometimes this requires adjusting the location by several meters and will not have a significant adverse impact on the operation plan for the system. Careful review of crossover and turnout locations during the preliminary engineering stage is an important step to minimizing potential for vibration impact. Another approach is to use special devices at turnouts and crossovers, special crossings (frogs) that incorporate mechanisms to close the gaps between running rails e.g. Swing Nose Crossing. These Crossings with spring-loaded mechanisms with movable points can significantly reduce vibration levels near crossovers.

7.3.3 Vehicle Specifications

The ideal rail vehicle, with respect to minimizing ground-borne vibration, should have a low unsprung weight, a soft primary suspension, a minimum of metal-to-metal contact between moving parts of the truck, and smooth wheels that are perfectly round. A limit for the vertical resonance frequency of the primary suspension should be included in the specifications for any new vehicle. A vertical resonance frequency of 12 Hz or less is sufficient to control the levels of ground-borne vibration. Some Metro systems recommend that the vertical resonance frequency of metro stocks to be less than 8 Hz.

7.3.4 Special Track Support System

When the vibration assessment indicates that vibration levels will be excessive, it is usually the track support system that is changed to reduce the vibration levels. Floating slabs, resiliently supported ties, high-resilience fasteners, and ballast/resilient mats have all been used in tunnels/subways to reduce the levels of ground-borne vibration. To be effective, all of these measures must be optimized for the frequency spectrum of the vibration. Most of these relatively standard procedures have been successfully used on several tunnel/subway projects. Applications on at-grade and elevated track are less common. This is because vibration problems are less common for at-grade and elevated track; cost of the vibration control measures is a higher percentage of the construction costs of at- grade and elevated track; and exposure to the elements can require significant design modifications.

Each of the major vibration control measures which can also be termed as Mass Spring System (MSS) for track support is discussed below. As the cost of these systems is usually sensitive to the level of mitigation they provide, it is important to have proper selection of the right system after necessary impact assessment to find the required frequency range and attenuation needed, based on the proven-ness for that range of the system. Performance criteria/Reference codes of some of these measures is given as **Annexure-B**

- **Resilient Fasteners**: Resilient fasteners are used to fasten the rail to concrete track slabs or ballastless bed. Standard Resilient fasteners are usually very stiff in the vertical direction, usually in the range of 35 KN/mm, although they do provide vibration reduction compared to some of the rigid fastening systems used on older systems (e.g., wood half-ties embedded in concrete). Resilient fasteners can be further sub divided into Low, Medium, High and Very High Resilience fastening systems depending on their design and level of resilience built-in and attenuation they offer. It is important to know target frequency spectra in which attenuation is needed to select the fastening system or any other mitigation measure. Special fasteners can reduce vibration by as much as 5 to 10 dB at frequencies above 30-40 Hz. Cost of high attenuation fasteners can be as high as 5 to 6 times that of standard fastening system.

- **Ballast Mats:** A ballast mat consists of a rubber or other type of elastomer pad that is placed under the ballast. The mat generally must be placed on a concrete base to be effective. They will not be as effective if placed directly on the soil or the sub-ballast. Consequently, most ballast mat applications are in subway or elevated structures.. Ballast mats can provide 10 to 15 dB attenuation at frequencies above 25 to 30 Hz. Ballast mats are often a good retrofit measure for existing tie-and-ballast track where there are vibration problems. For ballast less track forms, they need to be installed at the time of track construction.

- **Resiliently Supported Ties:** The resiliently supported tie system consists of concrete ties supported by rubber pads. The rails are fastened directly to the concrete ties using standard rail clips. Existing measurement data indicate that resiliently supported ties may be very effective in reducing low-frequency vibration in the 15 to 40 Hz range. This makes them particularly appropriate for transit systems with vibration problems in the 20 to 30 Hz range. Although most commonly used in slab track or subway/tunnel applications, another version of a resiliently supported tie system involves attaching thick rubber pads directly to the underside of ties in ballast.

- **Floating Slab:** Floating slabs can be very effective at controlling ground-borne vibration and noise. They basically consist of a concrete slab supported on resilient elements, preferred types of resilient elements are

  - Discrete supports (steel springs or elastomeric pads),
  - strip mats,
  - continuous elastomeric mats

  Floating slabs are effective at frequencies greater than their 'single degree of freedom' vertical resonance frequency though they can be designed to low frequency and high attenuation of ground borne vibration and noise.

- **Other Marginal Treatments:** Changing any feature of the track support system can change the levels of ground-borne vibration. Approaches such as using heavier rail, thicker ballast, or heavier ties can be expected to reduce the vibration levels. There also is some indication that vibration levels are lower with wooden ties compared to concrete ties in ballasted track territory.

  Note:
  The performance of individual generic track form cannot be added together to provide increased reduction of ground –borne vibration/ noise. It is possible for combined performance to be less than what is expected from individual track form. For instance, provision of resilient fastening system over floating slab track may adversely affect the reduction of ground borne vibration / noise what could have been otherwise achieved by providing floating slab with standard fastening system.

Table 7.2 provides typical natural frequencies which may be achievable from track forms with different elastic solutions discussed above. The values indicated have been obtained with interaction with trade and are only for guidance. Actual prototype testing or obtaining proven performance record is recommended for the given conditions for arriving at the exact values before deciding to use any elastic solution. Figure 7.1 provides typical curve for attenuation comparison by some elastic solutions vis-à-vis conventional ballasted track.

Table 7.2, Typical achievable natural frequency of track along with different elastic solutions

Elastic Solution	Achievable Natural Frequency of Track Support system
Elastic Fasteners	40 - 60 Hz
High Resilient Fasteners	28 - 40 Hz
Special Fasteners	20 - 25 Hz
Booted Sleeper	15 – 40 Hz
Ballast mats	15 - 22 Hz
Floating Slab with discreet pads	3 – 18 Hz
Floating Slab with Metal Spring elastic support	6-15 Hz
Floating Slab with strip resilient support	12-18 Hz
Floating Slab with continuous resilient support Mats	15-22 Hz

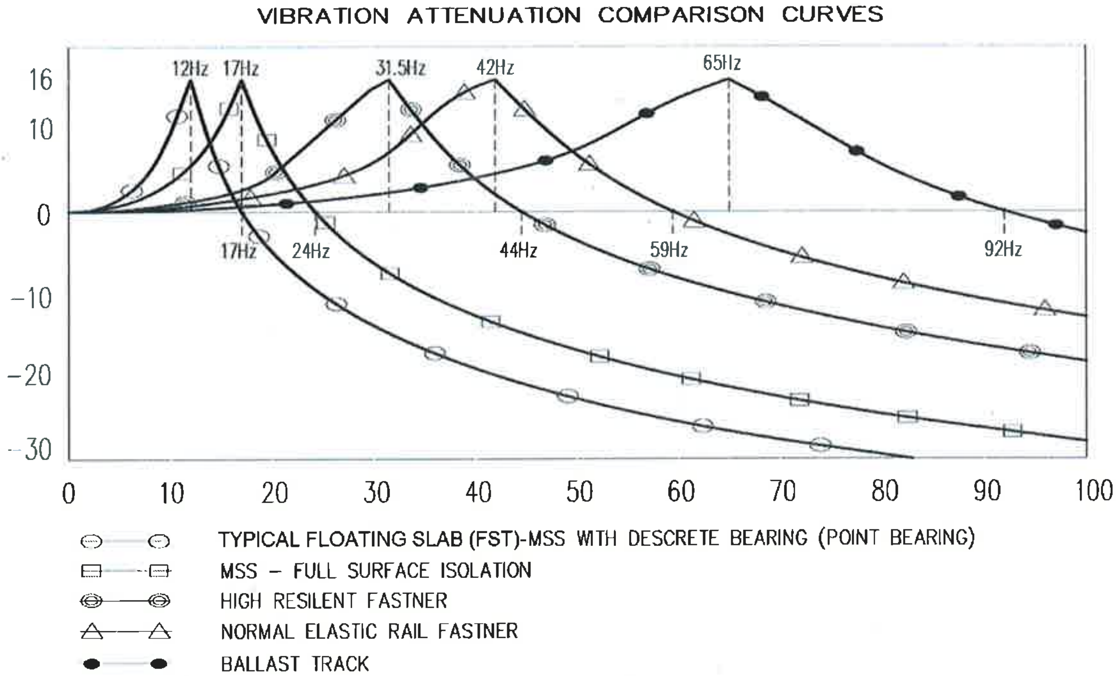

Figure 7.1, Attenuation of various typical elastic track forms under given conditions

It is to be noted that softer is the elastic solution, the resonance peak would be in lower frequency range. Similarly, harder is the elastic solution, the resonance peak would be in higher frequency range. It is therefore important to carefully choose the mitigation measure, as inappropriate vibration control measure selected may not only be ineffective but also may create additional track maintenance issues.

7.3.5 Building Modifications

In some circumstances, it is practical to modify the impacted building to reduce the vibration levels. Vibration isolation of buildings basically consists of supporting the building foundation on elastomer pads similar to bridge bearing pads. Vibration isolation of buildings is seldom an option for existing buildings; normal applications are possible only for new construction. This approach is particularly important for shared-use facilities such as office space above a transit station or terminal. When vibration-sensitive equipment such as electron microscopes will be affected by transit vibration, specific modifications to the building structure may be the most cost-effective method of controlling the impact. For example, the floor upon which the vibration- sensitive equipment is located could be stiffened and isolated from the remainder of the building to reduce the vibration. Alternatively, the equipment could be isolated from the building at far less cost.

7.3.6 Trenches

Use of trenches to control ground-borne vibration is analogous to controlling airborne noise with sound barriers. In certain favourable situations, trench building can be a practical method for controlling transit vibration from at-grade track. A rule-of-thumb given suggested in FTA document is that if the trench is located close to the source, the trench bottom must be at least 0.6 times the Rayleigh wavelength below the vibration source. For most soils, Rayleigh waves travel at around 180 m/sec which means that the wavelength at 30 Hz is 6 meter. This means that the trench must be approximately 4 meter deep to be effective at 30 Hz.

A trench can be effective as a vibration barrier if it is either open or solid. Testing of a trench filled with styrofoam has been done by one of the US metro systems and found it successful over a period of at least one year of observation. Solid barriers can be constructed with sheet piling or concrete poured into a trench.

7.3.7 Operational Changes

The most obvious operational change is to reduce the vehicle speed. Reducing the train speed by a factor of two generally reduces vibration levels approximately of the order of 6 dB. Other operational changes that can be effective in special cases are:

- Use the equipment that generates the lowest vibration levels during the night time hours when people are most sensitive to vibration and noise.
- Adjust night time train schedules to minimize movements in the most sensitive hours.

While there are tangible benefits from speed reductions and limits on operations during the most sensitive time periods, these types of measures are usually not practical from the standpoint of service requirements. Further, vibration reduction achieved through operating restrictions requires continuous monitoring and will be negated if vehicle operators do not adhere to established maintenance practices.

7.3.8 Buffer Zones

Expanding the rail right-of-way sometimes will be the most economical method of reducing the vibration impact. A similar approach is to negotiate a vibration easement from the affected property owners, for example, a row of single-family homes adjacent to a proposed commuter rail line. However, there may be legal limitations on the ability of funding agencies to acquire land strictly for the purpose of mitigating vibration (or noise) impact. These methods though prevalent on the advance metro systems may have limited applicability in Indian context in the present times.

Annexure-A: GLOSSARY OF TERMS

A-weighting – A standardized filter used to alter the sensitivity of a sound level meter with respect to frequency so that the instrument is less sensitive at low and high frequencies where the human ear is less sensitive. Also written as dBA.

Accelerometer – A transducer that converts vibratory motion to an electrical signal proportional to the acceleration of that motion.

Ambient – The pre-project background noise or vibration level.

Amplitude – Difference between the extremes of an oscillating signal.

Alignment – The horizontal location of a railroad or transit system as described by curved and tangent track.

At-grade – Tracks on the ground surface.

Automated Guideway Transit (AGT) – Guided steel-wheel or rubber-tired transit passenger vehicles operating singly or in multi-car trains with a fully automated system on fixed guideways along an exclusive right-of-way. AGT includes personal rapid transit, group rapid transit and automated people mover systems.

Auxiliaries – The term applied to a number of separately driven machines, operated by power from the main engine or electric generation. They include the air compressor, radiator fan, traction motor blower, and air conditioning equipment.

Ballast mat – A 50- 80 mm thick elastomer mat placed under the normal track ballast on top of a rigid slab or packed sub-grade

Ballast – Granular material placed on the track-bed for the purpose of holding the track in line and at surface.

Catenary – On electric railroad and light rail transit systems, the term describing the overhead conductor that is contacted by the pantograph or trolley, and its support structure.

Commuter rail – Conventional passenger railroad serving areas surrounding an urban center. Most commuter railroads utilize locomotive-hauled coaches, often in push-pull configuration.

Consist – The total number and type of cars, locomotives, or transit vehicles in a trainset.

Continuous welded rail – A number of rails welded together to form unbroken lengths of track without gaps or joints.

Corrugated rail – A rough condition of alternating ridges and grooves which develops on the rail head in service.

Crest factor - The ratio of peak particle velocity to maximum RMS amplitude in an oscillating signal.

Criteria – Plural form of "criterion," the relationship between a measure of exposure (e.g., sound or vibration level) and its corresponding effect.

Cross tie – The transverse member of the track structure to which the rails are spiked or otherwise fastened to provide proper gage and to cushion, distribute, and transmit the stresses of traffic through the ballast to the trackbed.

Crossover – Two turnouts with the track between the frogs arranged to form a continuous passage between two nearby and generally parallel tracks.

Cumulative – The summation of individual sounds into a single total value related to the effect over time.

Cut – A term used to describe a trackbed at a lower level than the surrounding ground.

dB – see Decibel.

dBA – see A-weighting.

Decibel – The standard unit of measurement for sound pressure level and vibration level. Technically, a decibel is the unit of level which denotes the ratio between two quantities that are proportional to power; the number of decibels is 10 times the logarithm of this ratio. Also written as dB.

Descriptor – A quantitative metric used to identify a specific measure of sound level.
DMU – Diesel-powered multiple unit. See Multiple Unit.

DNL – see Ldn.

Electrification – A term used to describe the installation of overhead wire or third rail power distribution facilities to enable operation of trains.

Embankment – A bank of earth, rock or other material constructed above the natural ground surface.

Equivalent Level – The level of a steady sound which, in a stated time period and at a stated location, has the same sound energy as the time-varying sound. Also written as Leq.

Fixed guideway – A mass transit facility with a separate right-of-way for the exclusive use of public transportation and other high-occupancy vehicles.

Flange – The vertical projection along the inner rim of a wheel that serves, together with the corresponding projection of the mating wheel of a wheel set, to keep the wheel set on the track.

Floating slab – A special track support system for vibration isolation, consisting of concrete slabs supported on resilient elements, usually rubber or similar elastomer.

Frequency – The number of times that a periodically occurring quantity repeats itself in a specified period. With reference to noise and vibration signals, the number of cycles per second.

Frequency spectrum – Distribution of frequency components of a noise or vibration signal.

Frog – A track structure used at the intersection of two running rails to provide support for wheels and passageways for their flanges, thus permitting wheels on either rail to cross the other. Also non as Crossing.

Gauge (of track) – The distance between the rails on a track.

Grade crossing – The point where a rail line and a motor vehicle road intersect.

Guideway – Supporting structure to form a track for rolling or magnetically-levitated vehicles.

Head-End Power (HEP) – A system of furnishing electric power for a complete railway train from a single generating plant in the locomotive.

Heavy rail – See Rail Rapid Transit.

Hertz (Hz) -- The unit of acoustic or vibration frequency representing cycles per second.

Hourly Average Sound Level – The time-averaged A-weighted sound level, over a 1-hour period, usually calculated between integral hours. Also written as L1h.

Idle – The speed at which an engine runs when it is not under load.

Intermediate Capacity Transit (ICT) – A transit system with less capacity than rail rapid transit, but more capacity than typical bus operations. Examples of ICT include bus rapid transit (BRT), automated guideway transit (AGT), monorails and trolleys.

Intermodal facility – Junction of two or more modes of transportation where transfers may occur.

Jointed rail – A system of joining rails with steel members designed to unite the abutting ends of contiguous rails.

L1h – see Hourly Average Sound Level

Ldn – Day-Night Sound Level. The sound exposure level for a 24-hour day calculated by adding the sound exposure level obtained during the daytime (7 a.m. to 10 p.m.) to 10 times the sound exposure level obtained during the nighttime (10 p.m. to 7 a.m.).

Leq – see Equivalent Level

Light Rail Transit (LRT) – A mode of public transit with tracked vehicles in multiple units operating in mixed traffic conditions on streets as well as sections of exclusive right-of-way. Vehicles are generally powered by electricity from overhead lines.

Locomotive – A self-propelled, non-revenue rail vehicle designed to convert electrical or mechanical energy into tractive effort to haul railway cars. (see also Power Unit)

Main line – The principal line or lines of a railway.

Maglev – Magnetically-levitated vehicle; a vehicle or train of vehicles with guidance and propulsion provided by magnetic forces. Support can be provided by either an electrodynamic system wherein a moving vehicle is lifted by magnetic forces induced in the guideway, or an electromagnetic system wherein the magnetic lifting forces are actively energized in the guideway.

Maximum Sound Level – The highest exponential-time-average sound level, in decibels, that occurs during a stated time period. Also written as Lmax. The standardized time periods are 1 second for Lmax, slow and 0.125 second for Lmax, fast.

Metric – Measurement value, or descriptor.

Monorail – Guided transit vehicles operating on or suspended from a single rail, beam or tube.

Multiple Unit (MU) – A term referring to the practice of coupling two or more diesel-powered or electric- powered passenger cars together with provision for controlling the traction motors on all units from a single controller.

Noise – Any disagreeable or undesired sound or other audible disturbance.

Octave band – A standardized division of a frequency spectrum in which the interval between two divisions is a frequency ratio of 2.

One-third octave band – A standardized division of a frequency spectrum in which the octave bands are divided into thirds for more detailed information. The interval between center frequencies is a ratio of 1.25.

Pantograph – A device for collecting current from an overhead conductor (catenary), consisting of a jointed frame held up by springs or compressed air and having a current collector at the top.

Peak factor – see Crest factor.

Plan-and-profile – Mapping used by transportation planners that shows two-dimensional plan views (x- and y- axes) on the same page as two-dimensional profiles (x- and z-axes) of a road or track.

Peak Particle Velocity (ppv) – The peak signal value of an oscillating vibration velocity waveform. Usually expressed in inches/second in the United States.

Peak-to-Peak (P-P) Value – Of an oscillating quantity, the algebraic difference between the extreme values of the quantity.

Power unit – A self-propelled vehicle, running on rails and having one or more electric motors that drive the wheels and thereby propel the locomotive and train. The motors obtain electrical energy either from a rail laid near to, but insulated from, the track rails, or from a wire suspended above the track. Contact with the wire is made by a pantograph mounted on top of the unit.

Pure tone – Sound of a single frequency.

Radius of curvature – A measure of the severity of a curve in a track structure based on the length of the radius of a circle that would be formed if the curve were continued.

Rail – A rolled steel shape, commonly a T-section, designed to be laid end to end in two parallel lines on cross ties or other suitable supports to form a track for railway rolling stock.

Rail Rapid Transit – (often called "Heavy Rail Transit") A mode of public transit with tracked vehicles in multiple units operating in exclusive rights-of-way. Trains are generally powered by electricity from a third rail or overhead catenary alongside the track.

Receiver/Receptor – A stationary far-field position at which noise or vibration levels are specified.

Resonance frequency – The phenomenon that occurs in a structure under conditions of forced vibration such that any change in frequency of excitation results in a decrease in response.

Right-of-Way – Lands or rights used or held for railroad or transit operation.

Root Mean Square (rms) – The square root of the mean-square value of an oscillating waveform, where the mean-square value is obtained by squaring the value of amplitudes at each instant of time and then averaging these values over the sample time.

RMS Velocity Level (LV) – See "Vibration Velocity Level."

SEL – see Sound Exposure Level.

Sound Exposure Level – The level of sound accumulated over a given time interval or event. Technically, the sound exposure level is the level of the time-integrated mean square A-weighted sound for a stated time interval or event, with a reference time of one second. Also written as SEL.

Sound – A physical disturbance in a medium that is capable of being detected by the human ear.

Spectrum – See Frequency Spectrum.

Sub-Ballast – Any material of a superior character, which is spread on the finished subgrade of the roadbed and below the top-ballast, to provide better drainage, prevent upheaval by frost, and better distribute the load over the roadbed.

Subgrade – The finished surface of the roadbed below the ballast and track.

Suburban bus – Bus similar to an intercity bus with high-backed seats but no luggage compartment, used in express mode to city centers from suburban locations.

Switch – A track structure used to divert rolling stock from one track to another.

Tangent Track – Track without curvature.

Track – An assembly of rail, ties (sleepers) and fastenings over which cars, locomotives, and trains are moved.

Traction Motor – A specially designed direct current series-wound motor mounted on the trucks of locomotives and self-propelled cars to drive the axles.

Trainset – A group of coupled cars including at least one power unit.

Transducer – Device designed to receive an input signal of a given kind (motion, pressure, heat, etc.) and to provide an output signal of a different kind (electrical voltage, amperage, etc.) in such a manner that desired characteristics of the input signal appear in the output signal for measurement purposes.

Transit center – A fixed location where passengers interchange from one route or vehicle to another.

Truck – The complete assembly of parts including wheels, axles, bearings, side frames, bolster, brake rigging, springs and all associated connecting components, the function of which is to provide support, mobility and guidance to a railroad car or locomotive.

Trunk line – See Mainline. The mainline of a commuter railroad where the branch line traffic is combined.

Turnout – An arrangement of a switch and a frog with closure rails, by means of which rolling stock may be diverted from one track to another.

VdB – see Vibration Velocity Level.

Vibration Velocity Level (LV) – Ten times the common logarithm of the ratio of the square of the amplitude of the RMS vibration velocity to the square of the amplitude of the reference RMS vibration velocity. The reference velocity in the United States is one micro-inch per second. Also written as VdB.

Vibration – An oscillation wherein the quantity is a parameter that defines the motion of a mechanical system.

Wheel Flat – A localized flat area on a steel wheel of a rail vehicle, usually caused by skidding on steel rails, causing a discontinuity in the wheel radius.

Wheel Squeal – The noise produced by wheel-rail interaction, particularly on a curve where the radius of curvature is smaller than allowed by the separation of the axles in a wheel set.

Annexure-B

Acceptance Guidelines/Reference Codes for Mitigation Measures

B.1 This annexures outlines general criteria which may be followed by metro railways for deciding on acceptance criteria once mitigation measures to be taken are decided based on the detailed study as brought out in various chapters of this document.

B.2 GENERAL

B.2.1 General requirements are stipulated in Annexure C-1 of the "PROCEDURE FOR SAFETY CERTIFICATION AND TECHNICAL CLEARANCE OF METRO SYSTEMS BY RDSO"

B.2.2 Proven Performance: The mitigation measures to be used should have proven performance of at least 7 years in one metro railway or 5 years in two metro railway systems (at least 16 Ton axle load and 80 kmph speed on standard / broad gauge track laid at least in a length of 200 mts) for more or less the same frequency spectra attenuating range for which the mitigation measure is proposed to be provided.

B.2.3 The prospective supplier/ vendor shall submit certificate from the reference Railway/ transit authority as per Performa enclosed at **Annexure- C**.

B.2.4 The prospective supplier / vendor shall also demonstrate through detailed calculations that the mitigation measure is able to achieve reduction of vibration and re-radiated noise, as the case be, conforming to target attenuation levels in the prescribed frequency spectra range, incorporating the type of civil structure, geological conditions, locations of the nearby habitations/buildings, type of rolling stock, etc.

B.3 FASTENING SYSTEMS:

If the target frequency spectrum and vibration/noise mitigation levels are such that it is considered by the client metros or demonstrated by the prospective suppliers that the same can be achieved by providing a resilient or high resilient fastening system on ballastless structures, the fastening should comply with Performance Criteria of Fastening System for ballastless track on Metro Railways/MRTS systems issued by Ministry of Railways, India (Annexure C-2 of the document mentioned in B.2.1 above). In case of any conflict or any additional provision which may be there on account of proposed fastening system's expected fitness to achieve the required N&V attenuation, the stipulation as received from the reference Railway/Transit authority certifying the proven-ness shall have precedence over provision of para B.2.1 above.

B.3 Supplier / vendor should be able to demonstrate the effectiveness of the mitigation measure installed after its installation that the output of the mitigation measures is within the limits as per codal provisions. The desired output from the mitigation measures especially natural frequency of the mitigation system and the permissible

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limits of variations shall be clearly spelled out by the client metro well in advance.

B.3 REFERENCE SPECIFICATIONS FOR GUIDANCE

Though the specifications, codes of practices, etc which shall be used for acceptance criteria, testing scheme/method, measurements, etc of various elements of prospective mitigation measure as well other related aspects shall be obtainable from the proven-ness reference as per para B.2.3, as a matter of general guidance for metro system, a list of various specifications, documents generally referred on the subject, is tabulated as under. It is preferable that the client metro follows one source of specifications e.g. either EN specs or German specs or ISO, unless and otherwise there is no equivalent specification available from that source for a given requirement.

S.No.	Number/Identification	Description
1	ISO-14837	Mechanical Vibration-Ground borne noise and vibration arising from Rail systems
2	EN 13481: 2012	Railway applications. Track. Performance requirements for fastening systems
3	DIN 45673	Mechanical Vibration: Resilient elements used in railway tracks
4	DB BN 918 071-1	German Railway norms for track/ballast mats
5	CEN-draft CEN/TC256/SC1/WG16/SG4	Railway applications / Track-Concrete sleepers and bearers – concrete sleepers with under sleeper pads
6	ISO 10846:2008	Acoustics and vibration -- Laboratory measurement of vibro-acoustic transfer properties of resilient elements
7	DIN 4150 T1 and T2	Structural Vibration
8	DIN 45669 T1-T3	Measurement of vibration emission
9	DIN 45672 T1 and T2	Vibration measurement associated with railway traffic systems
10	DIN 50100	Testing of materials; Continuous Vibration test; Definitions, Symbols, Procedure, Evaluation
11	PN ISO 37:2007	Rubber, vulcanised or thermoplastics – Determination of Tensile Stress-strain properties
12	DIN 2089 T1	Helical compression springs made from round wire and rod
13	DIN EN ISO 527	Tensile test with E modulus
14	ISO 1856: 2000	Flexible cellular polymeric materials– Determination of compression set.

S.No.	Number/Identification	Description
15	DIN EN ISO 868	Shore A and Shore D
16	ISO 3302	Rubber – Tolerances for products
17	ISO 1461:2009	Hot dip galvanised coatings on fabricated iron and steel articles
18	ISO 2768:1989	General Tolerances
19	DIN EN 10089	Hot rolled steels for quenched and tempered springs
20	DIN EN 13906	Cylindrical helical springs made from round wire and bar
21	EN 12087	Thermal insulation products for building applications – Determination of long term water absorption by immersion
22	EN 13230:2009	Railway applications – Track – Concrete sleepers and bearers
23	Review of existing standards, regulations and guidelines, as well as laboratory and field studies concerning human exposure to vibration	By Brend Asmussen, UIC dtd. 12/01/2011
24	Testing System in accordance with Art 53 RL 2004/17/EG, Feb., 2012	Elastic bearing in Mass spring systems, ballast mats and under sleeper pads by OBB Infrastructure, Austria
25	DIN EN 10204	The European standard Norm EN 10204 defines different types of test document which can be made available to the buyer for each delivery in compliance with agreements concluded on placement of order.

Annexure-C

Performance Certificate of the noise and vibration mitigation measures for metro rail transit systems:

SN	Item	Particulars
1	Name of the Metro Rail Transit System (MRTS) and line on which proposed mitigation is laid	
2	Operational speed of the MRTS	
3	Axle load of the MRTS	
4	Country in which laid	
5	Name and type of the mitigation measure i.e. Slab/ Strip/Blocks/ springs/ fastenings etc.	
6	Month and year of commencement of operation after installation of mitigation measure.	
7	Type of track Structure e.g. a) Ballasted/ballastless b) Tunnel/viaduct/At-grade c) type of track fastening system d) Base form e.g. plinth/slab; etc.	
8	Total length in which installed (meters)	
9	Vibration mitigation achieved along with frequency range (VdB) as designed and measured: (a) After installation (b) after a period of not less than 3 years after of installation, if available	
10	Acceptance Criterion and test protocol followed by the MRTS for the mitigation measures.	
11	Any problems encountered during installation?	
12	Any problems noticed after installation?	
13	Is the performance satisfactory as per the design criterion and as per client requirements.	
14	Any other comments on the performance on the performance of the mitigation measure	
15	Date of issue of this certificate by the MRTS	