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RAILWAY VIBRATIONS TRANSMITTED THROUGH THE GROUND AND THE EFFECT OF VIBRATIONS ON BUILDING CASE STUDY FROM ANKARA

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Abstract

At this reseach the causes of ground vibration, the manner in which they propagate through the ground and the effect of measures to reduce the vibraion amplitudes has investigated. This research also reviewed information and standards concerned with the sensitivity of building to ground vibration. Although anti-vibration measues have been deeloped which are effective for underground railway, it has proved difficult to find measures which can reduce the very low frequency vibrations associated with main-line railway in the open. Results from field trial with different forms of track construction have shown that a useful reduction in vibration levels can be achieved for track in the open but the mechanism involved are not fully understood since theoretical models are not fully developed. Studies of the response of lineside residents have shown people will complain at vibration levels well below those at which structural damage to buildings is likely to occur. However, lineside residents will tolerate higher levels of vibration than are indicated by existing international standards. The long term durability of some anti-vibration systems has been measured and found to be satisfactory; however, more needs to be done to assess durability and other aspects of the grouhd vibration phenomenon. Research has exemplificate with Ankara Metro and ANKARAY projects.

1. Introduction

This study began at 1989 with the begining of one period of Metro and ANKARAY Railway Mass transit system project. From that date on, several aspect of projects were researched like; excavation, construction methodology, water isolation method, effect of rail system to environment and city. Additionally effect of railwy and metro stations to city and near environmet were researched with different aspect like; effect of track noise to enironment from underground, from at gound and from over ground, effect of underground railway line's vibrationto environment, effect of at round and over ground railway vibration to environment with ground-borne noise way, effect of noise to passengers and near building residences' people, effect of railway vibration to passengers and near residences' people. These researces has three steps; 1) pre-research methods, preparing of before construction and preparing specification, 2) construction period research at as-build time and 3) operational period from time to begin to nowadays. This research is about railway vibrations transmitted throuhg the ground and the effect of vibrations on buildings which one part of these studies.

The public incoming increasingly sensitive to any form of environmental disturbance or pollution. Railways are commonly seen as less intrusive then roads or airports but there is nevertheless an increasing tendency to complain about railway induced noise vibration, especially when it is necessary to change traffic patterns or build new lines.
The work programme included the following studies covered by three steps:
1) generation and propagation of vibration
2) the effect of vibration on people and buildings, and
3) measures to reduce vibrations. The little of the study was changed to be "Vibration transmitted through the ground".
When research was first set up, concern over vibration was particularly strong amongst operators of underground railways and progress in evolving anti-vibration means was most advanced for these

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circumstances. Research concentrated at first on gathering data on the effectiveness of these measures and the reaction of buildings to vibrations. The test site, which required specially constructed track forms with ballast mats and sleeper soffit pads, was built at Mold Juntion on the London Midland region. Initial results from this test site were reported. A further site was established to test lineside damping masses at Worlaby on the Eastern Region. For the first step, it also presents further results obtained at Mold Junction after the track with ballast mats was modified to give greater ballast stability and includes a final brief review of the satus of theoretical work at the time of writing. Theoretical studies are seen as the principle means of optimising anti-vibration measures. Unfortunately, the theoretical models are not yet fully developed and validated. For the second step; at the construction period some measurements has been calculated. International standars for vibration effect on buildings are compated with measurements.

2. The Effect Of Vibration On Building

Vibation are coused by the large forces between wheels and rails. Lack of maintains and disrepairness increare this vibration and noise time to time. These forces fluctuate in responce to wheel and rail roughness over a wide range of frequencies.

In addition, the distribuitons of axle loads in a train also produces a force excitation as it passes a fix point. The latter effect leads to excitation at frequencies which correspond to the vehicle passing frequency and its harmonies, whereas forces due to the wheel or rail roughness have a periodicity determined by the wavelength of the roughness and the vehicle running speed.

Vibrations propagate from the track through the ground by means of compression waves, shear waves and surface (Rayleigh) waves. For each type of wave the energy become less as distance from the source increases owing to geometric dispersion and energy absorbtion in the ground The lowest frequencies are least damped.

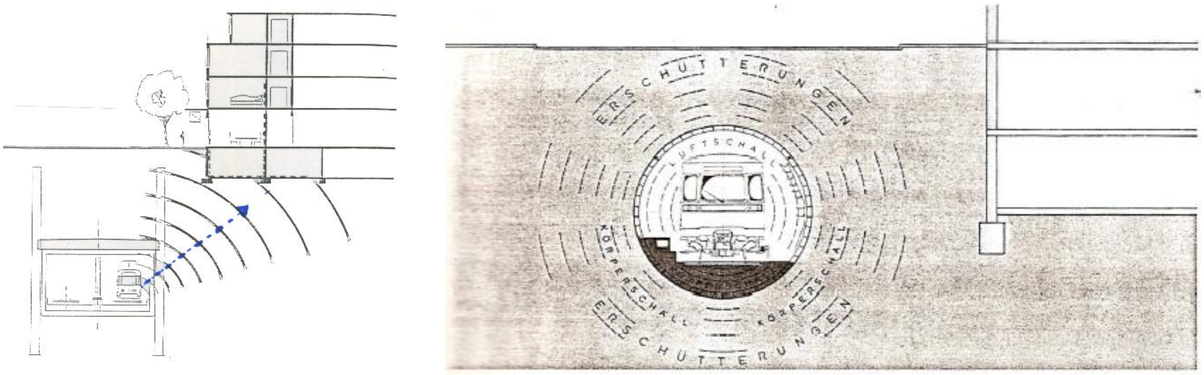

Figure 1: Ground-borne noise and vibration from underground railway to buildings. Examples from Duisbur and Vienna

Main lines in the open radiate vibrations via Raylrigh waves according to the mechanism sketch in Fig. 1. For underground railways the vibration energy is mainly transmitted in the frequency band 30 – 150 Hz. Through compression and shear waves as indicated in Fig. 2. These vibrations, most commonly having an energy peak in the ragion of 50 Hz. Are noticeable as a rumbling noise due to re-radiated sound from walls and ceiling vibrating typically at 5-25 Hz. Building near the line railways are usually at such a distane that vibrations due to compression and shear waes have decayed and only the surface waves remain.

The most critical conditions occur when the prdominant frequency of a ground vibration coincides with the natural frequency af a building. Although the fundamental frequency for lateral vibration is of the order of 1 – 10 Hz., components may have higher natural frquencies.

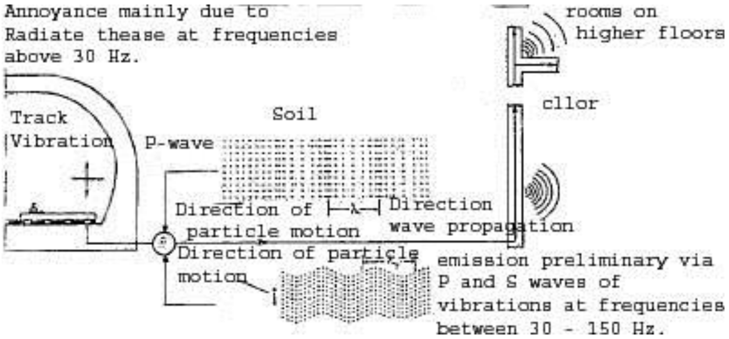

Figure 2: Vibration propogation by underground railways.

It is often found that larger vibration amplitudes are measured in the upper part of buildings than a the foundations. Measurements in timber houses near a heavy freight railway in Sweden have shown horizontal sway motions at relatively low frequencies (circa 5 Hz.) to be most noticeable, whereas measurements on masonry structures in many locations show the vertical resonances of floors (circa 25 Hz.) to be most noticeable. These comments apply principally to buildings near lines in the open; where buildings are situated over underground railways the most noticeable effect seems to be noise generated by vibration of the walls and ceilings (circa 50 Hz.). All these comments relate to the manner in which buildings subject to railway induced vibration create noticeable effects and larger vibration amplitudes; they do not relate directly to building damage. Many investigator have observed that people find vibrations unacceptable long before the vibration levels are such as to cause structural damage.

Even without any vibraiton, many buildings are in a state of stress due to differential settlements of the foundation or shrinkage of the fabric so it may be postulated that a small additional effect due to vibration could cause an acceleration of the deterioration. This effect must be very small, however, since as yet it has not been demonstrated to occur and the vibration levels associated with railways (usually less than 1 mm/sec) are generally much smaller than those associated with mining. The literature quotes values above which damage to property is probable. These vary from country to country from 2 mm/sec to 51 mm/sec. This variation covers many factors including whether cosmetic or structural damage is concerned, the type of construction and the intrinsic value of the building (e.g. ancient monument, etc.)

To provide some quantitative data on the vibration levels required to damage a masonry structure, the committee commissioned a test programme in which a series of L shaped walls were subjected to 60 days sustained vibration. The vibration level (14mm/sec peak at 13 Hz.) was set high at the reported threshold between “possibility of plaster cracks” and “probable damage to load bearing units”. Although a 25% reduction was observed in the natural frequency of the walls, only very trivial damage was observed. This consisted of minor cracking in the joints on the exposed brick face of the walls; there was no apparent cracking of the plaster surface. Clearly this test [3] can only be viewed as an initial attempt to explore this problem. More needs to be done to explore the effects of lower vibration amplitudes and particular stress raising features found in houses. Another area of study which justifies attention and has not been addressed by the consortium researher concerns the effect of vibraions on the compaction of ground beneath heavy foundation. A study of this topic should show whether vibrations can introduce uneven settlements if they are more severe on one part of a structure than another.

3. The Causes Of Vibration And The Manner Of Propagation

As wheels roll along he rails, irregularities in the roundness of the wheels or the smoothness of the track cause fluctuations in the wheel/rail forces. These will be referred to as “dynamic” forces, to distinguish them from the steady “static” forces due to the weight of the vehicle. Dynamic forces are the main source of ground vibrations. Even the very slight variation in stiffness along a track at positions over and between sleepers can crate dynamic forces. One other source of vibrations can arise due to a shock wave forming on very soft ground when the train speed exceeds the speed of Rayleigh waves. Fig. 3.

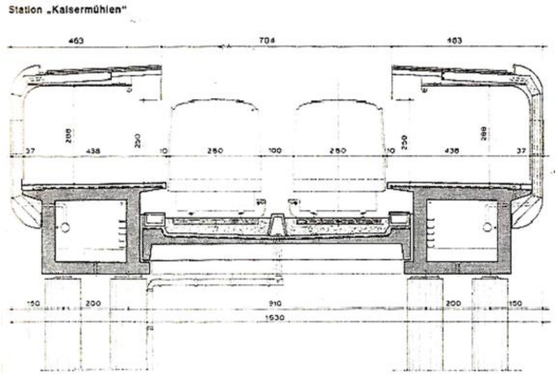

Figure 3: Kalsermühlen station

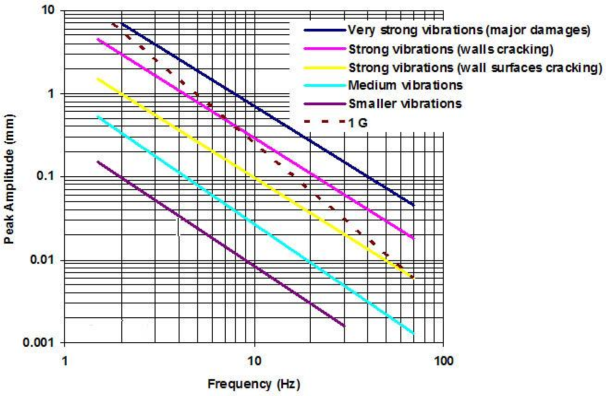

Figure 4: Effect of vibration on buildings

3.1.Roughness Induced Vibrations

Since the wheel and rail roughness can have a spatial spectrum of different wavelengths which defines a spectrum of different frequencies for a specified running speed, the excitation of the system is such as to produce dynamic forces at many differen frequencies. These forces then cause vibration in the ground which propagate in three principal types of wave: compression waves, shear waves and Rayleigh waves. The compression and shear waves propagate in three dimensions and decay with distance from the point of excitation more rapidly than the Rayleigh waves which propagate essentially as surface waves. Thus at distances of the order of 100 m. or more from the track for railways in the open, the Rayleigh waves will dominate. However, for building above an underground railway, compression and shear waves will be most important. The higher the frequency of vibration, the more rapid is the damping and decay in amplitude with distance from source. Thus at 100 m. or more from the track the ground vibrations are dominated by relatively low frequency Rayleigh waves, whereas above an underground railway, higher frequencies are likely to be most noticable, due to the nearness of the track and the greater sensitivity of the ear to acoustic radiation at high frequencies from the walls of buildings.

If vibration spectra are measured at the side of the track for a variety of vehicle passing speed and the peaks of the spectra are plotted against speed, a “Campbell Digram” results. Some peaks occur at a fixed frequency independent of running speed i.e. the excitation is caused by a particular wavelength of roughness. Some periodicities of the track stucture particular wavelength of roughness. Some periodicities of the track structure are easily recognised even with new track e.g. the sleeper spacing or harmonics of the rail length between welds or joints, others are due to waves in the rail arising in its manufacture. These latter are typically 1.7 m. or 2.2 m. Rails which have seen long service may develop waves in the vertical profile of the running surface due to uneven wear or plastic deformation, typically at wavelengths similar to sleeper spacing, and these may be significant. It is unlikely, however, that short pitch corrugations (typically 50 mm. wavelength) will give a significant ground vibration since the corrugation wave passing frequency is usually too high.

To understand the preferred frequencies in the Campbell Diagram is often difficult. A commonly observed frequency is that of the unsprung mass of the axle oscillating vertically on the resilience of the track (typically 50 Hz.), and another possibility is the oscillation of the entire vehicle mass on the track resilience. This latter is usually a sign that the vehicle suspensions are not flexing. A further possibility is that the ground has a layered structure which is favouring the propagation of waves of a particular frequency to the measuring point.

If a preferred natural frequency of the system should coincide with a frequency peak due to a wavelength of roughness at a particular running speed, then the ground vibrations at this frequency can become very strong. Under these circumstances an increase in speed will cause a reduction in vibration, but the general rend is for increased speed to increase speed to increase dynamic forces and hence ground vibrations. Clearly, the vibrations of most significance are those which can excite a response in the building. This is particularly true of vibrations in the range 20 – 30 Hz. Exciting floor vibrations in houses.

3.2.Effect of Vehicle Parameters

RATP was commissioned to carry out a study which aimed to determine the effec of certain parameters of railway dynamics of an underground line on ground-borne vibrations. This investigated the effects of the axle load, running speed, the unsprung mass of the running gear and the condition of the wheel tread.

It was concluded that variations in axle load had no significant effect, whereas variations due to speed were heavily dependent on the condition of the wheel treads of the train. With newly profiled wheels the variation due to speed only had a significant effect immediately next to the line (10 dB at the tunnel wall, 3 dB in adjacent building when the speed increases from 20 to 60 km/h) whereas with worn wheels, i.e. worn into waves with a typical wavelength of 200 to 300 mm (recent measurements carried out by RATP which have not been published by ORE), the effect of speed is significant 10 dB in an adjacent building for the same range of speeds) and extends to points quite a distance from the line as a result of significant low frequency spectral contributions. Data are now being analysed to determine the influence of a wider range of speeds on the vibrations. An increase in the unsprung mass reduces the resonance frequency of the mechanical system – unsprung mass/track resilience – which entails a corresponding reduction in the dominant frequency of re-generated secondary noises and may reduce the level of the noise expressed in dB(A).

A study of the condition of the wheel treads led to a comparison of the vibrations produced by trains running at a speed of 60 km/h in the following conditions:
a) newly turned wheels
b) newly turned wheels with slight wheel flats created artificially with a grinder.
c) wheels with tread worn in service (after 150 000 km) i.e. geometriclly imperfect treads (out of roundness, succession of waves or corrugations)
d) wheels worn in service (after 150 000 km/h) with flats deliberately developed by skidding (emergency braking with suppression of wheel – slide protection).

It was found that trains with newly turned wheels produced the lowest levels of vibration. Surprisingly, wheels with artificial flats did not give rise to a noticeable increase in vibrations. Although the impact of the flats on the rail could be heared at the trackside, the resulting high frequency energy was quickly absorbed in the ground and scarcely reached lineside buildings. Wheels with treads showing pronounced wear showed a significant increase in vibration levels in comparison with newly turned wheels at frequencies below 100 Hz. This was probably due to the “roughness” of the wheels at wavelengths in the range 0.2 to 0.3 m. which causes vibrations at these frequencies and speeds. This type of roughness can also be emphasised by the spalling out of tread materil due to thermal damage which is than followed by plastic deformation which widens and reduces the depth of the depressions. Wheel flats created by skidding prduce a further increase in vibration levels at frequencies above 80 Hz. This occurs at frequencies which are low enough to be able to penetrate adjacent buildings can produce an acoustic effect (+ 5 dB(A). A significant difference is observed between the effects of the flats and those produced by a grinder, probably because the natural process not only gives rise to a localised abrasion of the profile but also causes the adjacent part of the profile to rise with a transfer of material. [12]

Concerning he influence of running speed, this has been shown to depend on the distance to the observation point and on the structures trough which the waves pass. At low speeds, a factor of 3 in speed can cause an increase in vibration of between 3 and 10 dB. The greatest increase occurs when the wheels are worn and irregular. Data on the effect on vibrations of running at high speeds is only now being obtained.

3.3. Vibrations Due To Sleeper Spacing

As a wheelset moves along the track it encounters a slight variation in vertical stiffness over and between sleepers. This stiffness variation excites vertical motion of the wheelse at the sleeper passing frequency and harmonics of this frequency, and the dynamic forces which are generated will create ground vibrations. In addition to this, the transfer of an axle load to the ground via discrete sleepers can create ground vibrations at the sleeper passing frequency. This effect will be most powerful if the bogie wheelbase and vehicle dimensions are such as to cause the static axle loads to generate a strong harmonic at sleeper spacing.

4.Reducing Vibrations Due To Underground Railways

4.1 Resilience Of The Rail Fastenin System

Independently of the reduction in dynamic wheel/rail forces and ground-borne vibrations by the reduction of roughness of wheels and rails it is also possible to effect the vertical stiffness of the track to reduce the dynamic forces arising from contact roubhness.

At low frequencies, for example less than 20 Hz., the suspension of the vehicle is much softer than that of the rail; in other words the unsprung masses have a lower mehanical impedance than that the rail and consequently the roughness effects are absorbed mainly by the deflection of the suspension. Thus, unless a very marked reduction is obtained in track stiffness, the reduction of low frequency dynamic forces will be very small.

At higher frequencies, i.e. above 100 Hz. The inertia of the wheelset causes the mechanical impedance to rise progressively with frequency until it exceeds the track impedance, the effective mass of the track being usually much smaller. In this frequency range the track stiffness is important and increased resilience achieves an appreciable reduction in dynamic forces. In summary a soft rail support system leads to a reduction in high frequency dynamic wheel/rail forces and a reduction in the resonance frequency of the system consisting of he unsprung mass, moving on the resilience of the track.

The existance of the natural frequency of the system is particularly important for underground railways since it can produce very high maximum levels in the spectra of vibrations and noise emitted by the walls of buildings. A very soft track structure and a unsprung vehicle mass allow the natural frequency to be reduced to the point where the above-mentioned acoustic radiation lies outside the sound range. Owing to the difficulties in developing tack systems with low axle loads, such as rapid transit systems. The “ Cologne egg” system is an example of track with a soft rail support system. RATP has carried out comparative measurements of vibrations from ballasted track, both with and without this systems. The mean vibratory reduction for an underground type axle is of the order of 10 dB between 50 and 125 Hz. This causes quite a minor reduction in the level of secondary noise radiated by the adjecent structures. According to its designers, however, the system is said to be more efficient on a concrete slab. Table 1 shows that the highest levels of vibration are generated by compactors, vibratory rollers and pile driving.

Table 1: Approximate generated vibration levels for various sources.

Activity	Typical levels of ground vibration
Vibration rollers	Up to 1,5 mm/s at distance of 25 m.
	Higher levels could occur at closer distances; however, no damage would be expectated for any building at distance, greater than approximately12 m. (for a medium to heavy roller
Hydtalicrock breakers (levels typical of a large rock breaker operating in hard sandstone)	4.50 mm/s at 5 m 1.30 mm/s at 10 m 0.4 mm/s at 20 m 0.10 mm/s at 50 m
Compactor	20 mm/s at distances of approximately 5 m, 2 mm/s at distances of 15 m. At distances greater than 30 m, vibration is usually below 0.3 mm/s
Pile driving/removal	1 to 3 mm/s at distances of 25 m to 50 m depending on soil conditions and the energy of the pile driving hammer These levels are well below the threshold of any possibility of damage to structures in the vicinity of these works. At closer distances to the piling operations, some compaction of loose fill would occur due to vibratory effects

Bulldozers	1 to 2 mm/s at distances of approximately 5 m. At distances greater than 20 m, vibration is usually below 0.2 mm/s
Air track drill	4 to 5 mm/s at a distance of approximately 5 m, and 1.5 mm/s at 10 m. At distances greater than 25 m, vibration is usually below 0.6 mm/s, and at 50 m or more, vibration is usually below 0.1 mm/s
Truck traffic (over normal (smooth) road surfaces)	0.01 to 0.2 mm/s at the footings of buildings located 10 to 20 m from a roadway
Truck traffic (over irregular surfaces)	0.1 to 2.0 mm/s at the footings of buildings located 10 m to 20 m from a roadway

4.2. Resilience In The Track Structure (i.e. Below A Slab Or Sleepers)

To understand the effect of resilience in the track structure it is useful to consider an elementary mass/spring system. The resilience is defined by stiffness k, damping b and supports a mass m. the system has its own natural frequency f_o and the transmissibility represents the proportion of the dynamic wheel/rail force which reaches the ground beneath the resilient layer. There is an increase in the transmitted force and vibration due to the resilient layer for frequencies lower than $\sqrt{2}$ f_o but for higher frequencies there is a significant benefitin reduced force and vibrations. This simple picture may lead to an under estimation of the advvantage of such systems since the track, being situated above the resilient layer, acts to some extend as a beam which reduces the transmitted excitation, partly by interference between the signals produced by different wheels and partly by dispersion along the track. In many partical instances the resilient layer is placed beneath a concrete slab, which allows the mechanisms described above to operate fully.

The resilient material can be placed against the lower side of the sleepers and provides a certain degree of insulation by the mass/spring effect. In principle the greater the mass of the sleeper, the higher the efficiency of the device. The device can be used doth for ballasted track and concrete track. The latter version, used underground by RATP, is described in and achieves an improvement of 12 dB in comparison with a ballasted track in the range between 20 and 200 Hz. One improvement used widely by underground railways takes the form of resiliently mounted slabs whose resonant frequency, of te order of 15 Hz., depends on the stiffness of the resilient material used. In practice these measures have produced attenuations of 12 dB between 20 and 40 Hz. 18 dB between 40 and 125 Hz. And 25 dB between 125 and 500 Hz. In comparison with traditional ballasted track. [2]

For ballasted track on underground railways resilience can be supplied either by pads placed against the lower side of the sleepers or by mats underneath the ballast and these offer similar advantages to those obtained using resiliently mounted ballastless track. The use of softer mats or pads gives a greater reduction in vibration but the softness must be limited to prevent the rail deflection becoming excessive. The flexibility of mat may deteriorate as a result of the filling of cavities in the mat by particles produced by abrasion of the ballast. In the long term, the resilience could thustent to diminish since these abrasion products migrate naturally to the bottom of tha ballated bed and progresively fill the hollows in the mat which give it its flexibility. On this basis, designs which do not allow ballast penetration would be preferable. This problem does not arise with sleeper soffit pads; however, the risk of wear or puncturing of the pads cannot be eliminated despite hard protective layers but replacemet should be relatively easy.

It was concluded from this investigation that sleeper soffit pads offer a useful means to reducing vibrations on existing lines and ballast mats are more suitable for reducing vibrations on new lines with ballast.

When constructing underground railway to include anti- vibration measures, the designer must always try to predict their long-term effectiveness. To throw light on this the committee gathered together data on the current performance of anti-vibration systems installed in Europe in the past (the earliest being installed in 1968). The result of this survey are presented. It was concluded that, in general, the characteristics of the rubber resilient materials have not changed significantly but some of the ballast mats showed signs of reduced effectiveness, compared to conventional ballast track. This reduction may relate to different ageing of the ballast in conventional track and track with a mat since it has been observed that vibrations reduce with time when the track is laid normally and this reduction is less on the track with anti-vibration measures has continued to provide a satisfactory level of vibration control.

4.3. Re-turning Of Wheel And Grinding Rails

The bennefit of newly turned wheels in reducing vibrations have been shown in Fig. 9 It is now necessary to consider the effect of grinding the rails. Since this relates directly to the magnitude of the dinamic forces it is to be expected that halving the amplitude of he rail roughness will produce a similar reduction in the magnitude of the ground-borne vibrations with wheels in good conditions. Clearly a slightly less advantgeous result can be expected in the case of non-maintained (rough) wheel and also because of the effect of oscillations due to the periodic support of the rails. Although grinding systems are used on underground lines, the elimination of the relatively longwave roughness is judged to be difficult since the grinding stones tent to follow the rail profile. Thus, only small vibration reductions are achieced.

5.Vibration Reduction

Vibration protection measures are largely confined to modification to the track structure in tunnels and to additional measures in the ground under or alongside tracks on open terrain.

The common principle in all thesystems used in tunnels is to support the track mass by a resilient spring. The mass-spring systems act as a barrier to vibrations with a frequency greater than √2 times the natural frequency. For an undamped 1 mass-spring system the dynamic amplification V, being the ratio between dynamic and static force, or dynamic and static displacement, equals:

$$V = \frac{1}{1-\left[f/f_n\right]^2} \qquad \text{Equation 7}$$

In which f_n is the naturel frequency and f is the frequency of the excitation. The vibration reduction W can be expressed as:

W = 1 – V Equation 8

Fig. 3 shows both the amplification and the vibration reduction versus frequency for a natural frequency of 10 Hz. The vibration reduction in dB reads:

$$w_{dB} = 20\log\frac{1}{V} \qquad \text{Eguation 9}$$

$$w_{dB} = 40\log\frac{f}{f_a} \qquad for\,\frac{f}{f_a} \geq 3 \qquad \text{Eguation 10}$$

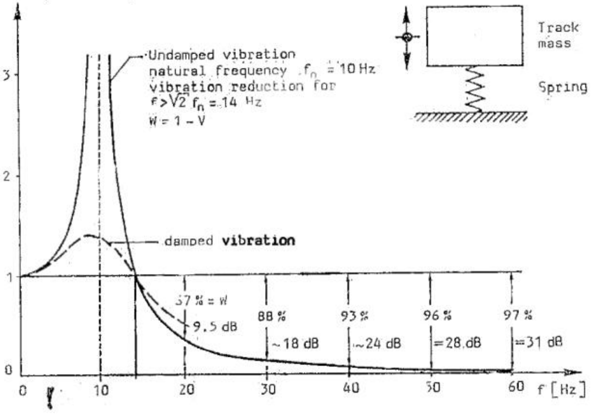

Figure 5: Principle of vibration reduction

5.1. Measures For Ballasted Tracks

with ballasted tracks vibrations may be reduced by increasing the ballast depth. DB tests have shown a reduction of 6 dB at frequencies below 10 Hz. By incresing the ballast depth from 30 to 75 cm.

Installing resilient mats between the bottom of the ballast and the tunnel invert, as sketched in Fig. 6. , has been employed as an anti-vibration method for a number of years. Basically three types of mat may be identified.

- Profiled mats: usually consisting of single or multi-layer configursted rubber layers;
- Granular mats; made for instance from old tyres bonded with a high-grade elastomer;
- Foam mats; consisting of single-layer or multi-layer polyurethane foam whose flexibility may be altered by changing to ratio of open cell to closed cell pores.

The rubber layers produce damping by changing the motion of ballast and not as a result of significant energy absorbtion within the layer itself. The project is to introduce resilience and hence generate a mass-spring effect carrying away energy. Maximum attenuation is obtained when the mats are as soft as possible.

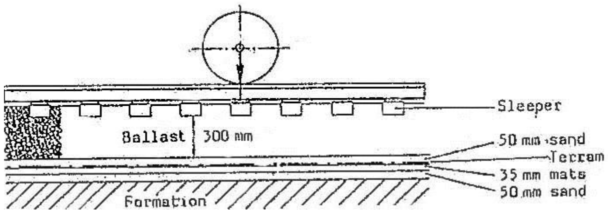

Figure 6: Ballast mats

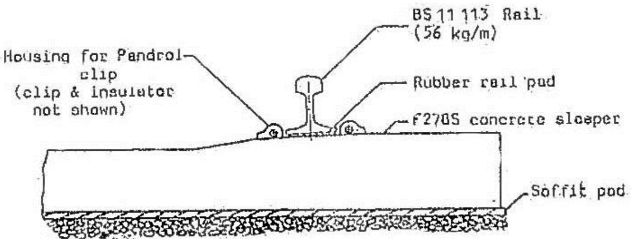

Figure 7: sleeper soffit pad

However if they are too soft problems arise because of increased rail streesses od de-stabilizing of the ballast requiring frequent tamping. Under a 25 tonne have load the quasi-static track deflections should give about 3 mm at 3 Hz., with limiting deflection of 4-5 mm under a static load. [16]

Ther solutions are sleeper soffit pads with the pads between sleeper and ballast acording to Fig. 7 The composite pad comprises 22 mm of rubber-loaded cork, with a hard facing the prevent damage by the ballast particles.

Fig. 8 summarizes experimentally determined sample transfer functions describing vertical vibration reduction versus frequency. The behaviour is quite familiar and their effectiveness is largely at frequencies above 30 Hz.

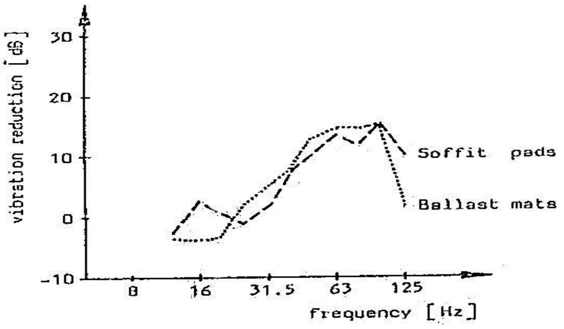

Figure 8: Vibration reduction achieved by ballast mats and soffit pads.

5.2. Relation Standards About Vibration

There is no Australian Standard currently for assessment of building damage caused by vibrational energy. However, the British Standard 7385: Part 2 1993: Evaluation and measurement for vibration in buildings can be used as a guide to assess the likelihood of building damage from ground vibration.BS7385 suggests levels at which 'cosmetic', 'minor' and 'major' categories of damage might occur. Further to this, the German Standard DIN 4150 – Part 3: Structural vibration in buildings – effects on structures, also provides recommended maximum levels of vibration to reduce the likelihood of building damage caused by vibration. In most cases, the generated vibration levels are too low in magnitude for the likelihood of structural damage to occur for buildings greater than 25 m from the construction activity. Given the proximity of residential buildings adjacent to the proposed Northern Expressway alignment, structural damage is not probable.

6. Case Study From Turkey

Ankara Metro Railway System and ANKARAY Light Rail system's vibration and noise effects on the side buildings of line similar to other vibrations which discussion before. As seen at Fig. 9 metro tracks creating high noise and vibration when entrance to tunnel and especially train horn accelerating the noise and vibration at this time, but for the decceleration period noise and vibration also descelarion.

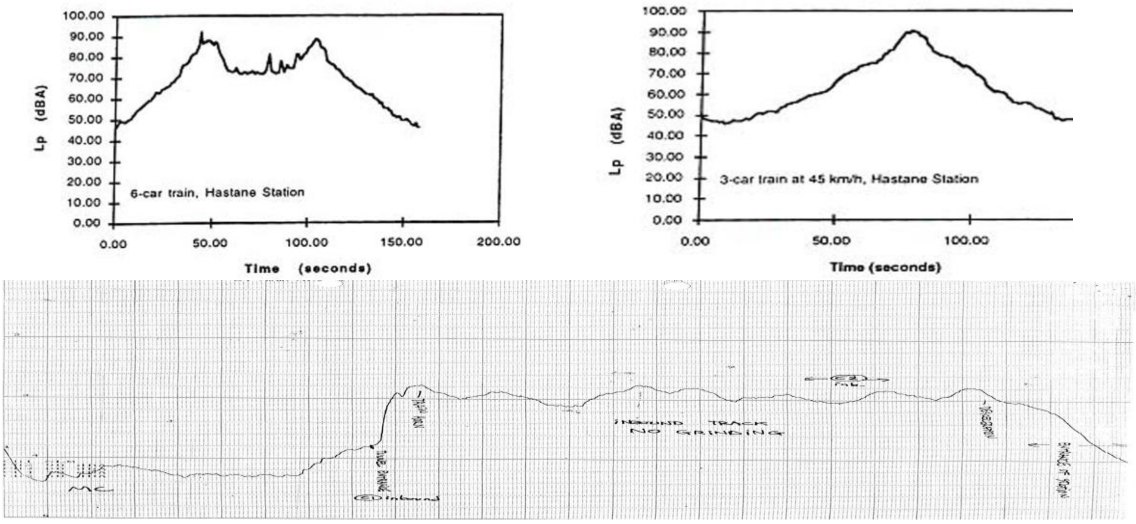

Figure 10: Acceleration and desceleration period noise and vibration SPL differencies.

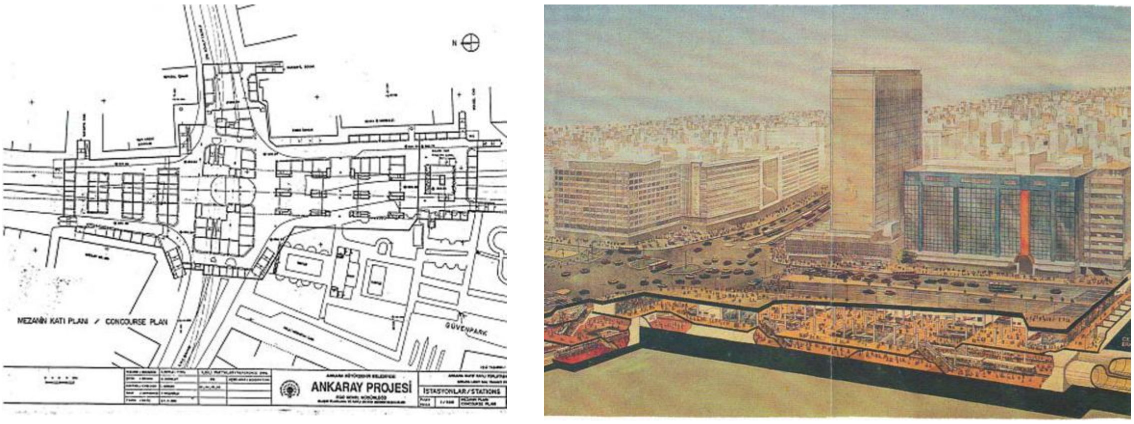

Figure 11: Kızılay Metro abd ANKARAYShared Station Mezzaninne plan with side buildings and sketch of Kızılay station with side buildings.

As seen Fig. 9 metro station is between the highrise buildings. Measured vibration levels are not upper of recommended vibration criterias of 2-10 Hz in between Kızılay-Sıhhiye line. . Whole days. This is because in near future risk on building from vibration is not seen. But, Ankara Kızilay Station example is one side of research, which have new bulildings which resistant to continual vibration. This researh is not includin the effect of historical or local buildings.

Ankara Metro Line ANKARAY Light Rail System Line

Metro Kızılay –Sihhiye Line Metro Demetevler Stat. Line ANKARAY Demirtepe Line

Figure 12: Ankara Metro line crossing the mass building zone

At researced, vibration measured between 10 – 100 Hz and 2-15 dB on side line of Ankara Metro and ANKRAY Light rail. Changing of vibration are changing according to tracs (line) conditions and placement. Ivedik Station line is elevated line, because of the oscillation vibration frequencies are low bur SPLis higher than underground line. Additionally at the beginning clamber slope vibration and noise frequencies higher than plain un gradient line.

Table 2: Several types of trains' vertical vibrations, maximum Acceleration and Aproximate RMS Accelerations in Turkey [4]

Force	**Train Type**	**Efficient Max. Acceleration (g)**	**Approximate RMS Acc. (g)**
Diesel	Mavi Train	0.50 g.	0.35 g.
	Bogazici Train	0.18 g.	0.13 g.
	Dogu Express	0.16 g.	0.11 g.
	Ege Express	0.09 g.	0.06 g.
	Marchandize	0.08 g.	0.06 g.
	Meram Express	0.03 g.	0.02 g.
	Test Train	0.02 g.	0.01 g.
Electric	Elect. Train	5.	3.

As seen in Table 2, some types of trains vibrations had been researched in Izmit with TUBITAK (The Scientific and Technological Research Council of Turkey) These researhes showed that especially old types of trains vibrations are much more effective than new types but especially rail condition diretly effecting the RMS. Here we saw that there are directly relation between trains efficient (main) maximum acceleration and approximate RMS Acceleration.

7.Conclution

As seen in the research; many cities which having railways have vibration problems. Vibration is the problem for the side buildings construction not only as an trachoma effect at building walls' capillary fissure but also effecting installations like dirty and clean water pipe, heating systems, ventilation, electronicsystems … etc. As seen in Fig. 4 some levels of peak amplitudes effects the building walls which strong vibration reason the wall cracks. As seen Fig. 5,6,7 some expedience can use for reduction of vibration. Typical ground vibration from road, bridge and railway construction activities occurs in the frequency range of approximately 8 Hz to 100 Hz. Within this frequency range, building contents such as blinds and pictures would commence visible movement at 0.5 mm/s. At vibration levels higher than 0.9 mm/s, rattling of windows, crockery or loose objects would be audible and annoying. Given the proximity of residential buildings adjacent to the proposed Northern Express way alignment, this vibration symptom is not likely to occur for the majority of residents.

Relation standards shows that there is some lack in national and international standards. For the understanding the effect of vibration to the side buildings construction and on people, national and international standards have to expand and improve about vibration. Especially historical buildings much more effecting than new buildings.

Some expediences effecting the ground borne vibration. (Fig. 10, 11, 12) As an example in Ankara, Merto lines have agregas under ballasts, and this system induce increasing indoor noise level and vibration. Sleepers, as metion chapter 5.1 abatement noise and vibration frombogie, track and wheels. At ANKARAY Light Rail System, sleepers and pads are used. When comparing Ankara Metro and ANKARAY system seen that Ankaray system line's noise and vibration level is much more acceptable than Metro line. Research is continuing about the effect of these vibrations' and noises' effect on historical and locak buildings.

References

1. ORE C 143 "Environmental pollution by the railways" Netherland, April 1976,
2. ORE (S 1013) "The effect of low frequency vibrations in the soil". April 1977
3. ORE Com. D 151 "A new to establish a baic understanding of the problem.April 1979,
4. TUBITAK research groups work, Izmit, 1998
5. ISO 2631
6. Esveld Coenraad "Modern Railway Track" Metro Consortium Specialist Works Duisburg, 1965
7. ISO 2631 (1978) "Guide for the Ealuation of Human Exposure to Whole Body Vibration"
8. Anonym, "Fahren auf neuen Wegen" Duisburg, Doch , 1989.

9. Bachmann H. And Ammann W., „Vibrations in structures induced by man and machine“, Structural Engineering Documents 3e, IABSE AIPC – IVBH, ETH Hoeggerberg, Zürich, Switzerland.
10. Heynen G. W.J.: “Railway induced vibrations” (in Dutch), Internal NS report (CTO), November 1987.
11. Fredrick C. : “Vibration in ground: Railway indeed ground vibrations’, Rail International /Schienen der Welt, October 1987.
12. ORE D 151 rp2: “An assesment of vibration counter-measures in current use” Utrecht, April 1989.
13. Esveld C.: “Einige Erfahrungen mit dem dynamischen Gleisstabilisator (DTS) bei den NS’, Glasers Annalen, November 1980.
14. ORE C 137 rp12: “Railway noise: Measurements of the running noise caused by train on different types of bridges”, Utrecht, April 1981.
15. Alias J.: “Le Rail” Eyrolles, Paris, 1987.
16. Fredrick C. O. : Vibrations in ground : Railway indeed ground vibrations’, Rail International / Schienen der ;Welt, October 1987.