Environmental Dimensions of Underground Space Use

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ABSTRACT

The need of promoting underground space use in urban areas has been emphasised as it helps in promoting infrastructure development that is less damaging to environment and simultaneously improves the standard of living. Environmental dimensions of underground space use include impact identification and assessment, health, safety and efficiency of workers and various legal regulatory framework as described in this paper.

Correlation of environmental dimensions/ parameters with various sustainability characteristics have been studied. A case record of vibration effect due to underground metro system has also been given to explain the importance of environmental impact studies.

1. INTRODUCTION

In 21st century three major areas namely *space, ocean and underground* are going to assume significant importance for human activity. Developing countries, like India had already established good credentials in *space* and *ocean* but the third major field, i.e. *underground* is yet to be explored at depth. *Underground Space* is one such area, which has tremendous potential for civic needs in developing countries for shelters, recreation, traffic, like oil/gas storage, commercial activities, etc.

Underground space is nothing but the creation / construction of grottoes, voids or earth sheltered like sub-surface space particularly in those areas where the surface land is scarce.

From concept to commissioning, such engineering creations have various positive and negative environmental and socio-economical impacts on existing environment and ecology of the region or area in which the facility is created. Number of technical, non-technical, constructional, financial, and social parameters (also termed in the paper as dimensions) govern their applicability to site specific conditions.

An overview of sustainable development principles in relation to use of underground space (Roberts, 1996) revealed that the underground space uses were stepped up in early 1980’s to cope up the modern pace of development. Surface network / infrastructure in limited land space of urban areas has become complex and overcrowded because of population growth which compelled the city planners and designers to go underground. India, being the second largest populated country in the world has no other options left but to adopt underground space for its civic needs. Considering the pros and cons of various available alternatives, it is the high time to gear up sub-surface applications in civic areas of urban locality.

As such evaluation of environmental parameters, which include impact identification and assessment for different problem areas becomes an important consideration for site selection and construction of various civic facilities. The evaluation of underground environment particularly worker’s health, safety and efficiency (hereinafter referred as HSE) is yet another important and influencing factor. Associated with HSE aspects are ventilation, underground drainage, lighting, control of noxious and harmful gases, which need proper attention and study. The site selected for underground space development should therefore also be seen from different perspective considering following points.

- acceptability to society,
- benefits over existing local / regional network or infrastructure,
- degree of isolation, terrain condition, elevation; and
- year round accessibility / approach.

Environmental factors have been dealt in the following paragraphs in detail and its correlation with sustainability has been studied.

2. ENVIRONMENTAL DIMENSIONS

Environmental dimensions of underground development include one or more than one of the following areas:

- Lowering of regional or local ground water table as a result of underground excavation work particularly when the excavations are large. *(This may happen due to unwanted connections between different aquifers in a regional hydrological system),*
- Subsidence of surface strata,
- Contamination / pollution of ground water,
- Environmental impacts due to ground vibration, when blasting is conducted or while the facility is in operation;

- Management of huge amount of excavated muck generated for disposal, and
- Socio-economic impacts on the health and living conditions of people due to working below ground e.g. long-term cut off from solar energy spectrum.

These areas which has potential environmental impacts can be studied on the basis of four distinct criteria viz. location, depth, method of developing underground space and its functional uses (see box below).

Environmental Impact Studies Criteria

Location of Underground Space

- Urban areas with dense population
- Urban area with less population
- Areas (other than urban) with less population and surface space in plenty

Depth of Underground Space

- <10m Shallow
- 10m – 30m Medium
- 30m - 50m Deep
- >50m Very deep

Method of Underground Space Development

- Open cut excavation for earth shelter structures
- Underground excavation for cavern or tunnel structures

Functional Use of Underground Space

- Shelters /Housing/stores/basement /godown /office building etc.
- Public use such as sports, recreation, town hall, cultural shelter etc.
- Traffic parking, road tunnel etc.
- Technical uses such as power plants, multipurpose tunnels, waste water treatment / disposal plant, fuel storage, defence installations etc.

The soil/rock is a medium in which sub-surface constructions are made. Influence of soil / rock properties on sub-terranean construction is yet another grey area of research which has relation with environmental parameters e.g. *thermal conductivity, heat retention and resistance to freezing / heating*. The ability of a specific soil / rock to gain or loose heat or cold, affects the design for seasonal/diurnal thermal changes (Golany, 1990).

2.1 Environmental Impact Identification and Assessment

The industrial policy statement of July 1980, recognised the need for preserving ecological balance and improving living conditions in the urban centres of the country (MOEF, 1994). For all developmental projects (located on surface) there exists a set of guidelines for preparation of environmental impact assessment (EIA). To prevent pollution arising out of developmental activity and to contain it in limited areas preliminary and detailed impact assessment needs to be done depending on the size of developmental work. A simple flow chart (Fig.1) describing the steps to be followed in general has been given here.

EIA, a strong tool for impact studies is meant to encourage the consideration of the environment in planning and decision making and to ultimately arrive at actions, which are more environmentally compatible. An ideal EIA system is one, which apply to all projects, and addresses all those impact that are expected to be significant. EIA results into a crisp and clear *Environment impact statement* (EIS) which conveys the importance of the likely impacts and their specific characteristics.

Preparation of the EIS by EIA process in context to sub-surface applications helps as follows.

- It helps to build clean and green land surface in civilian areas, which turned to be the concrete jungles.
- It encourages inclusion of environmental considerations by developers and thereby reducing pollution.
- It helps in identifying interests and trade-offs.
- It helps in identifying management and mitigation measure.
- It facilitates better decisions, which are environmentally friendly.

An *integrated multidisciplinary approach* for impact identification and assessment is a must for complete solutions to the problems of underground space development as they are quite significant for cleaner environment - the greatest requirement of urban society. Therefore, environmental impact studies should be carried out on the site-specific basis keeping in view the basic principle of sustainability. To implement environmental practices in actual field conditions a guideline shall be kept ready. This guideline must contain both environmental management and EIA aspects. Following points are important in this context -

- Comprehensive EIA process for underground civic uses;
- Risk management;
- Appropriate environmental monitoring and environmental data management;

- Appropriate mechanism for preservation of natural resources encountered during underground space development

Since underground space and promotion of its use in urban areas is an emerging area it may not be misappropriate if, the lacuna of existing EIA procedure mainly framed for surface features are discussed briefly. One can learn lessons from the constraints of the existing EIA procedure, which is though elaborate but lacks strong teeth and is weak on the front of implementation. Constraints to EIA process can be attributed to simplicity of framed regulatory mechanism, fragmented authority among government agencies, uncoordinated decision making, practical applicability and the lack of technical and financial resources of regulatory agencies.

As said earlier that EIA is not only an impact study instrument but is a strong decision making tool too. Thus, the EIA process can influence public policy in a variety of ways. One such policy influence might be on permit requirement associated with project approval. These requirements may take the form of pollution control and impact mitigation measures, operational cycles and construction practices and timing, pollution control equipment specification etc. In addition, and again depending upon the nature and scope of the project an impact study can also lead to the delineation of *long term* environmental impact assessment and monitoring requirements which is essentially required for planning and future development.

2.2 Health, Safety and Efficiency (HSE)

Underground space utilisation for different kind of human activities are widely practised all over the world since decades. There are number of direct and obvious practical benefits of utilising underground space (Carmody and Sterling, 1993) which include from land saving to energy saving costs. But, when space is utilised for functions that involve human occupancy initial reactions are often negative. A wide range of concerns and questions are raised on health, safety and efficiency (HSE). These important environmental dimensions are commonly referred as *psychological effects of underground space*. Acceptability of the environmental conditions in sub-surface space by the peoples working therein is purely a psychological phenomenon and well manageable on case to case basis. If technically sound and efficient management systems are functional efficient, there is no danger to human life.

The claustrophobic feeling of living and working below surface arises even when there are no fundamental problems. To emphasise further on HSE aspects, an example of age old operation of *mineral extraction in the underground mines* may be quoted, where large human workforce are engaged in and working safely and conveniently. In the similar fashion underground space are also designed for healthy and safe working conditions where efficiency of the person remains unaffected.

It may also be noted that the underground openings are very safe from damage by earthquakes of even very high magnitude. The damage is near faults and seams only. Thus seismic safety is important advantage of underground structures.

Generally, HSE aspects are classified on the basis of nearness to surface. In deeper facilities (entered through long shaft or tunnels) the negative aspects of being underground are likely to be greater. Buildings/ underground spaces located, close to the surface i.e. at shallow depth has almost similar environmental conditions (geothermal gradient doesn't come in picture). Near surface structures can be connected to the ambient environmental conditions that exists on surface in various ways like earth sheltered houses hillside exposure etc. and problems about exposure to solar light and ventilation can be solved economically and conveniently.

Though, relatively little research has been done on the HSE aspects (Shukla, 2000) but responses of peoples to underground environmental conditions were studied scientifically and it is proven that as the person gets acclimatised to changed environment there exist no problem for working or living in sub-surface space. It is beyond doubt that there exists pressing need for more R&D in this important area.

2.3 Legal Regulatory Framework and Administrative Issues

In India, there is no separately designed legal and administrative frame-work/guidelines for underground space. Prevalent environmental act, rules and regulations, various mining laws as applicable to mines and administrative clauses applicable for different land areas are applied for underground space application. If, the underground space uses are to be promoted further it is necessary to have a suitable national policy framework. Legal and administrative guidelines may act as significant supporting barriers to the development and use of underground space. One major resistance of promotion of such uses is legal framework rather than technological or economical. A preliminary survey report of International Tunnelling Association (ITA) prepared for underground space uses could be extremely helpful for this purpose (Barker, 1991).

Thus, untapped potential for new legislation exist in respect of application / use of underground space. Scope for amendments of the prevalent rules, acts and regulations, which can be made applicable to Indian geo-environment exists. For sub-surface planning and policy initiative following statutes will be important -

- Relevant clauses of Environment Protection Act, 1985.
- Relevant clauses of Environment Protection Rules, 1986.
- Relevant clauses of Air (Prevention and Control of Pollution) Act, 1974

- Relevant clauses of Air (Prevention and Control of Pollution) Rules, 1981
- Relevant clauses of Water (Prevention and Control of Pollution) Act, 1974
- Relevant clauses of Water (Prevention and Control of Pollution) Rules, 1975
- Relevant clauses of Mines Act, 1955

Major administrative issues includes:

- Sub–surface ownership,
- Limits of surface and underground property,
- Natural mineral resources rights lying below ground –Whose Property is this? (currently, all such resources are the property of state/federal government),
- Who is responsible for safety, environment control and sub –surface land use planning, and
- Administrative requirements for regional and local city planning purposes.

3. CORRELATION WITH SUSTAINABILITY

Major contributions had been made in the past in underground construction works with a view to safeguard the future generation from urban congestion. *Sub-surface civic facilities* and *Earth sheltered habitats* built for various urban needs (Golany, 1990) is a one significant example. In context with underground space uses, a large number of indicators mentioned below are the magnitudes of sustainable development principles -

- Air, water and land quality protection and preservation
- Deforestation magnitude, vegetation, cutting trees, etc. due to underground construction activities
- Impact on atmospheric environment
- Dampness and high humidity in underground structures where maintenance of drainage system is poor
- Reduction in waste generation at source
- Pollution control and its potential effect on human life
- Quality of life and its improvement
- Health, consumption, settlements, security, transport, communication and human rights aspects
- Education, employment, poverty alleviation, culture
- Industry and economy

In what way and to what extent the above mentioned aspects are superior/inferior over surface alternatives should be evaluated on case to case basis to arrive at the final decision whether the use of underground space is sustainable in true sense or not.

Standard of Living / Quality of Life: It is evident that there exists correlation of underground construction with basic principle of sustainability. In order to correlate the environmental impacts with standard of living one should take into account and analyse the variety of accrued benefits by sub-terranean structures. If the urban areas are designed underground the indirect benefits are more compared to the surface alternatives. These benefits may be -

- There is land saving.
- There is more safety for people.
- There may be energy saving, as the subterranean structures are energy efficient. This in turn causes the better quality of life.
- There is a decrease in transportation and therefore fall out in vehicular pollution load.
- There is saving in time, reduction is outside nuisance.
- There is an increase in social interaction.
- There is saving of lengthy utility networks.
- There is reduction in negative environmental impacts.

Since, underground construction works have solved diversified problems, which the surface structures has created, they offer better rating in terms of higher quality of life. Subterranean placements are extremely effective in regions with extreme climatic conditions such as very warm or very cold. After the construction is completed and the site has regained its equilibrium such uses offer minimum surface disturbances and thus has a minimal impact on the existing ecosystem. Besides, the offered benefits, standard of living also depend on energy and environmental factors, which are multidimensional and dynamic in nature (Carmody and Sterling, 1993). These are favourable with particular reference to underground space use.

4 VIBRATION EFFECT DUE TO UNDERGROUND METRO SYSTEM -A CASE RECORD

A case record has been given here to learn and lay emphasis on what possible consequences may be faced on the front of environmental damage by the Mass Rapid Transport System (MRTS).

Vibration study had been performed for Zilina Slovak Railway (ZSR) in Slovak Republic to know the effect of train movement on urban surface structures and understand the process of vibration generation. It had helped the authorities to design the surface structures accordingly. The experimental tests were performed in the test fields of ZSR railway (Bencat,1995). The dimensions of the track and ground were as follows:

- Welded rails – 50.0 kg/m, m length;
- Tie – pre-stressed concrete tie, weighing 250 kg;
- Tie pad – rubber, thickness of 6 mm (elastic constant of 600 KN/cm);

- Ballast – crushed stone with depth of 350 mm;
- Roadbed – embankment of 250 cm & ground clay of 50 cm (p=1982 kg/m^3) and sandy gravel (p= 2050 kg/m^3) of 10m with water level at 4m beneath ground surface.

In the railway track of ZSR line, many pickups were attached to the rail (Fig. 2), the ties, ballast and wooden piles driven into the roadbed and ground and the accelerations of the vibrations were recorded using portable notebook computer (PC/386) with software and hardware facilities. The records obtained in the field using a frequency analyser BK-2131 and PC/386 were analysed. In Fig.3 results of one of the spectral and correlation analysis of the accelerations of the vibrations induced in the rail, the tie, roadbed and ground are shown.

Based on the experimental analysis of the railway track and ground vibrations, the following summary and conclusions were made:

- The results of the experimental measurements indicated that the analysis of random ground vibrations due to railway traffic movement provides a useful and required information on the frequency spectral characteristics of ground vibration, the vibration characteristic of soil, the surface wave velocities propagation, the soil attenuation co-efficient, damping parameters as well as the visco-elastic properties of soil

- From the spectrum analyses of the accelerations of the vibrations induced in the rail, the tie, the roadbed and the ground we can observe that the second peak is found at frequency of 80 Hz. Fig. 3a (near the welded rail joint) but in Figs. 3b, 3c the second peak cannot be found at the same frequency. In comparison of these figures one see that the accelerations of the vibrations with lower frequencies induced in the rail are transmitted to the ties and the roadbed with little damping, but the vibrations with the frequencies over 120.0 Hz are transmitted downwards with large damping coefficient.

- Power Spectral Densities (PSD) of the ground transmitted Rayleigh's waves indicate higher damping in the higher frequencies e.g. over 80.0 Hz. It proves the visco-elastic properties of the ground and roadbed, respectively. In the Fig.3d and 3e the peaks of the PSD are in the range frequencies from 20.0 Hz to 80.0 Hz, which indicate significant influence of the vibrations induced after the impulse into the track and ground.

- Experimental and theoretical analysis shows that three kinds of vibration are induced in the track and the roadbed by the application of the impulse. The first kind of vibration is the stationary vibration, which continues with constant amplitude and a fundamental frequency. The second kind is represented by the sum of the waves, which propagate along the rail. These waves have the frequencies, which are larger than the fundamental one and range in some intervals. The third kind is represented by the sum of the waves, which propagate in the downward direction with various frequencies. The range of the frequencies is from the maximum value involved in the second kind to infinity. Experimental analysis has proved that when the spring constant of the tie pads increases and bed materials become more softer, neither the first nor the second kinds of vibration exist and only the impulse is induced.

4.1 Process of Vibration Generation and Wave Propagation

The rail structure has many features, which are capable of generating / supplementing the basic vibration field (a stress field) beneath the train e.g. train weight, wagon axle load and the eccentric wheel load on the track. The track itself does not provide uniform support. The operation or movement of rail (supported on sleepers and placed at regular intervals, which in turn rest upon store ballast) is expected to contribute to the vibration disturbances, which will propagate to the ground on sides. Clearly some of these will produce a purely local effect in the case of isolated areas while other will provide a regular vibration pattern. The extent or magnitude of vibration will be dependent on the speed of the train, weight of the vehicle plying and structure strength adjacent to it. The experimental evidence point out that the impacts from the wheels passing over the rail joints have significant influence on ground vibration transmitted from railway to nearly regions.

Once transient stress variation are produced in the ground below the track they will propagate away from the track as ground-borne vibration. A variety of modes of vibration are possible within the ground and the principal types are the *Compression waves, shear waves and Rayleigh's waves*. In the ideal case when the ground is homogenous the compression and shear waves propagate in all directions away from the source and hence suffer substantial geometric attenuation as well as losses due to the damping properties of the ground. The Rayleigh's waves, being surface waves do not suffer the same geometric attenuation, but are still subject to loss by damping. In practise, the ground is far from homogenous, it may well be stratified and posses discontinuities homogenous, it may well be stratified and posses discontinuities. In such cases additional modes of vibration can propagate along the interfaces of the strata and mode conversion from one type of wave to another may be encouraged. The various modes have different propagation velocities. The compression waves travel at typically 1000 m/s. While the shear and Rayleigh's waves are much slower. Velocities are seen to be of the order of 200 m/s. But Rayleigh's waves have been reported as slow as 35 m/s. The vibration energy is not shared equally among the modes. Because of different geometric attenuation, the Rayleigh's wave carries most of the vibration energy at significant distances away from the track. A further significant factor is that high frequencies are attenuated much rapidly than low frequencies, so that low frequencies dominate the spectrum at distances more than a few metres from the source. With the complication of so many modes of propagation, and the wide variety of geological conditions over which railways have to be built, it would not be surprising if track side measurements at different sites produced a range of vibration values which bear no resemblance to each other. The past experience in terms of vibration acceleration level (linear over the range 2Hz to1000Hz) made on a variety of sites in Slovakia, yields just the confused picture (to be expected). Both the levels of vibrations and the manner in which the level decays with distance vary in a manner, which has so far defied prediction.

5. CONCLUSIONS

Analysis of various environmental dimensions of underground space uses and case record from archives as described in this paper it may be learnt that –

- Underground space uses offer enhanced living standards with better control over environmental conditions.
- The environmental problems encountered can be tackled easily if, the impacts are identified correctly and appropriate management measures are taken. Multidisciplinary understanding and sound environmental management practises based on the principles of sustainable development will certainly help in accelerating the underground utilisation compare to surface.
- An intimate correlation exists with sustainability, which promotes higher quality of life.

In brief, it may be concluded that urban areas have tremendous potential and immediate applicability of underground space for various known reasons. Over the last two decades the path is paved for integration of sub-surface structures in urban planning in India. Since the surface amenities are already overburdened with different kind of environmental and pollution related problems (due to excessive use of resources), inadequate infrastructure and population pressure, the necessity of sub-surface use for implementation can not be ignored easily. It is author's strong belief that the psychological barriers put a damper on tendency to opt for underground uses and should be dealt appropriately by the planners.

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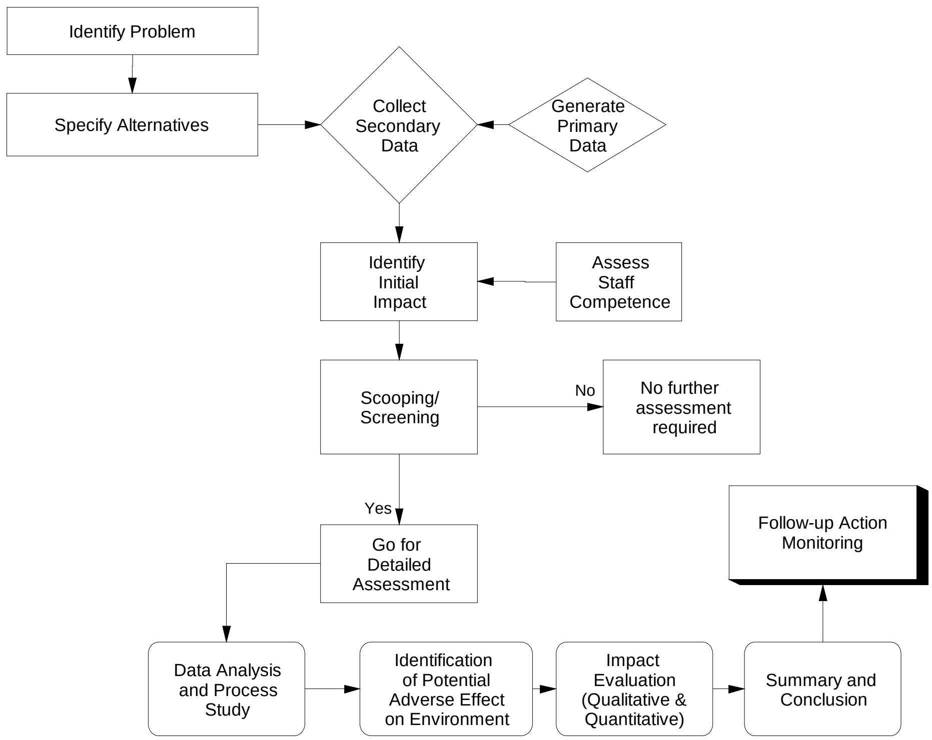

Fig. 1: A flow chart showing steps for environmental impact identification and assessment

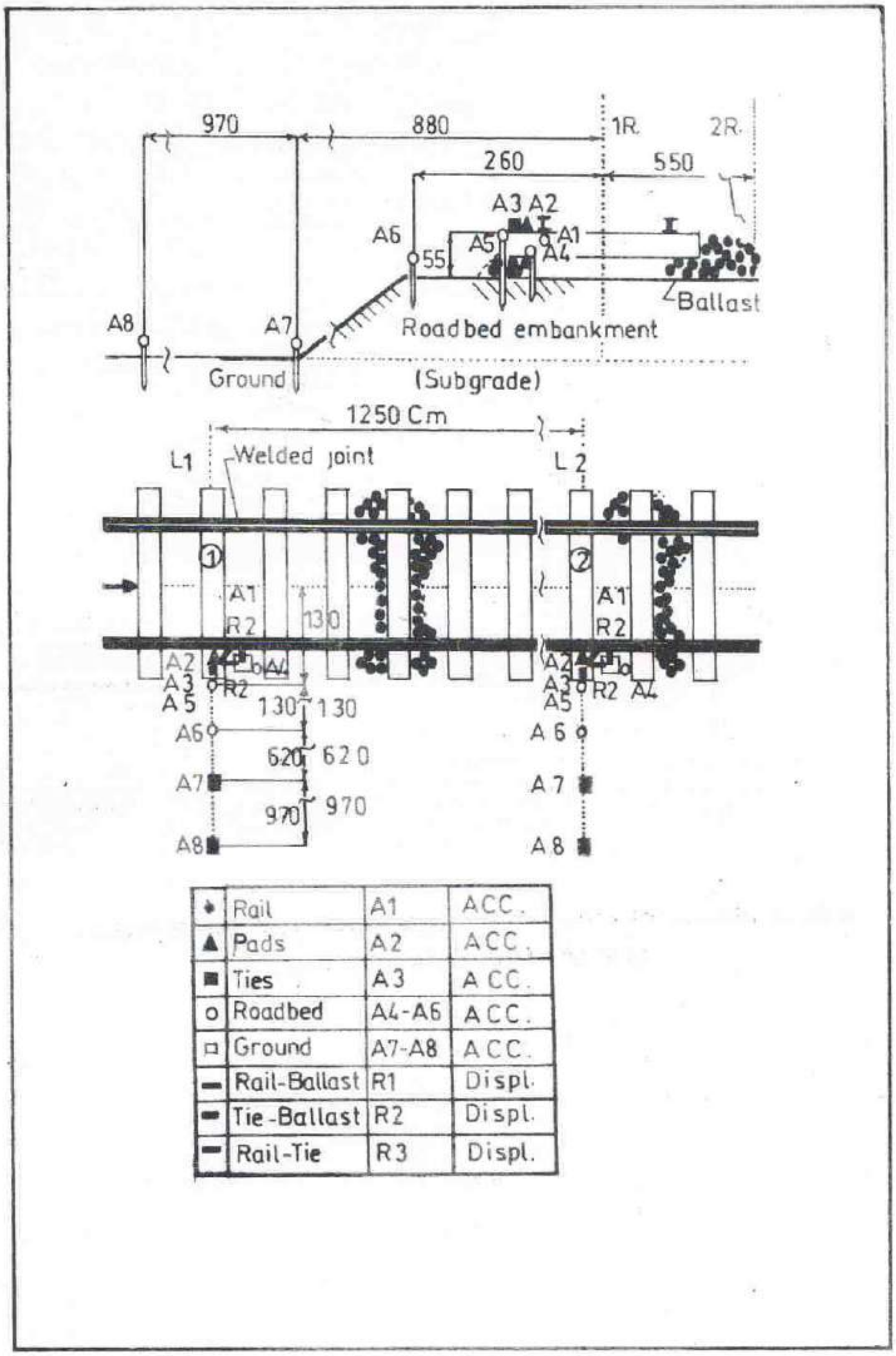

Fig. 2: A cross section of the railway track of ZSR line

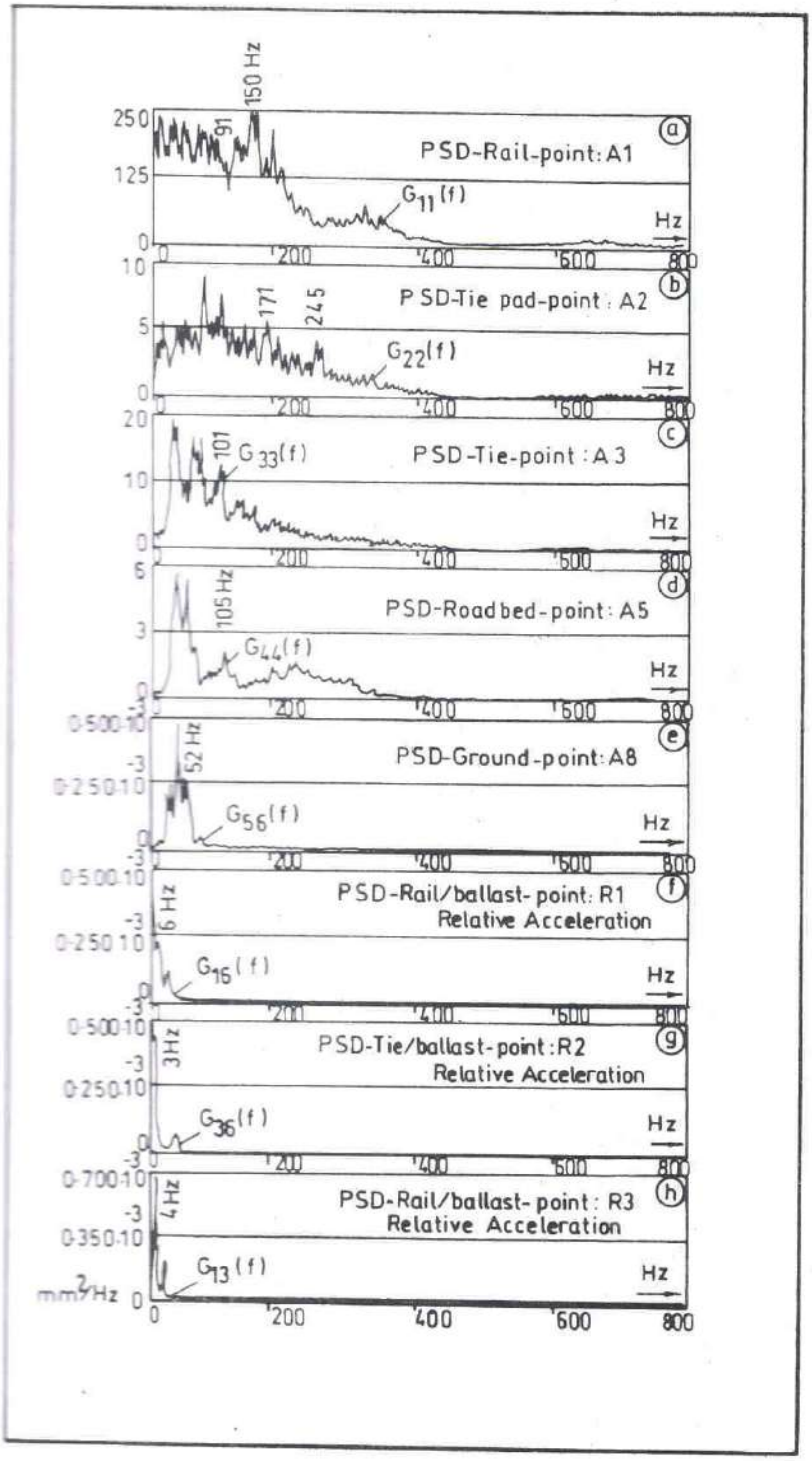

Fig. 3: Power spectral densities of the vibration acceleration in different points of the railway structure and adjacent ground