TRAFFIC-INDUCED BUILDING VIBRATIONS IN THE DISTRICT OF COLUMBIA

PHASE 1 DRAFT REPORT

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Submitted by:

Howard University Transportation
Research Center
2366 6th Street, NW
Washington, DC 20059

Submitted to:

Office of Transportation Planning
DC Department of Transportation
2400 14th Street, NW
Washington, DC 20009

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OVERVIEW

This report presents the activities conducted by HUTRC in investigating traffic-induced vibration and its impact on residential structures in the District of Columbia. The research is of long term nature and is being conducted in three phases. Phase 1 is the principal focus of this report and presents the investigation conducted by HUTRC, culminating in an experimental plan for conducting field investigation at sixteen (16) sites in Washington, DC. Phase 2 will involve the actual implementation of the research plan developed in Phase 1. Phase 3 will involve the development, implementation and evaluation of techniques to reduce the impact of traffic-induced vibrations on residential structures. It is envisaged that vibration mitigating measures will be implemented within the public right-of-way. Innovations in pavement design practices are likely to be developed, implemented, and evaluated in Phase 3.

PROBLEM STATEMENT

Trucks, transit buses, and other heavy commercial vehicles have been noted in citizen complaints about vibration and cracking of residential structures in the District of Columbia. Traffic-induced vibrations can be a source of discomfort and nuisance to residents. Vibration is a complex phenomenon that involves the interaction of vehicle and pavement systems. Traffic vibrations can be induced by heavy vehicles passing over discrete irregularities in the road surface (e.g., potholes, cracks, etc.) and periodic and random road surface irregularities, as well as by imperfect and inherent characteristics of the suspension system of heavy vehicles. Soft silty-clay soil, below pavements and houses, can serve as the medium for propagating vibration waves beyond the source, into adjacent property.

In response to numerous complaints from citizens and the desire to find plausible solution(s) to this problem, DDOT engaged the Howard University Transportation Research Center (HUTRC) to investigate traffic vibration and to develop measures for vibration control. DDOT initially charged HUTRC to investigate this problem at only two (2) sites while utilizing the complaints data, and pavement and geological data that were provided by DDOT. The project is conducted in three phases. Phase 1 involves a comprehensive literature review, field visits for observing site characteristics, an assessment of the geological data provided by the City and developing an experimental plan based on the expanded scope requested by the City. Phase 2 involves the implementation of the experimental plan developed in Phase 1. The work program conducted in Phase 1 is presented in this report. Phase 3 will involve the design, implementation and evaluation of solutions based on recommendations of Phase 2.

Preliminary review of all the complaints received by DDOT regarding traffic vibrations revealed that they are widespread across the City. It was therefore agreed that the experimental sites be expanded from two (2) to sixteen (16), in order to achieve a better representation of the geographical areas where traffic vibrations were reported. This decision was agreed to, based on factors such as variation in soil composition, pavement condition, type of housing and traffic classification across the City.

LITERATURE REVIEW

The vibration of residential buildings could be air-borne or ground-borne and could be caused by both internal and external sources. Common internal sources are machinery. HVAC Systems, elevators and the activities of occupants. External sources include earthquakes, wind, blasting, and construction operations, and road and rail traffic.

Vibrations in buildings caused by road traffic are generally not immediate health and safety concerns but are more of a problem of annoyance. People living in houses usually complain if the vibration levels are only slightly above the perception threshold. The ultimate major concern is the fear of eventual damage of the building and its contents. Vibrations may also interfere with sensitive processes such as those in hospital operating theaters, scientific research laboratories and high-tech industries. Three standards have been published that provide guidance for evaluating human response to building vibrations [1]. These are standards published by International Organization for Standards (ISO 1989), British Standard Institute (BSI 1993) and Acoustical Society of America (ASA 1983). These standards deal mainly with continuous and intermittent vibration such as that induced by blasting. However, the standards are not clear abut how to evaluate traffic-induced vibrations, which have relatively short duration and complex amplitude characteristics.

Currently, alternative evaluation methods are being developed by researchers of the Institute for Research in Construction (IRC) (and others) which are focused primarily on measurements of traffic vibrations at several complaint sites [1]. Preliminary traffic-induced vibration studies reveal that the vibrations experienced in buildings are largely dependent on the characteristics of the:

(a) housing
(b) vehicle
(c) soil and
(d) pavement structure.

Generally, structures are built according to specified standards referenced in building codes. Vibration levels experienced in, say a structure for dancing (e.g., dance club), may be different for one primarily used for lying (e.g., hospital) under similar location conditions. Buildings generally tend to vibrate at well-defined frequencies. Whole-structure frequencies range from approximately 10 Hz for low-rise structures to below 1 Hz for tall structures (e.g., ten stories). Depending on the type pf frame in a structure, vibration levels may be high or low. For wood framed residential structures (light walls), vibration frequencies range between 10 and 25 Hz and possibly up to 50 Hz for masonry [2].

Vibrations produced by road traffic tend to range from 5 to 25 Hz. The trigger for these vibrations is the traffic on the roadway. Heavy vehicles (buses and trucks) are generally thought to produce higher levels of vibrations in structures. Passenger cars and light trucks rarely induce vibrations that are perceptible in buildings. The composition of traffic on the roadway would therefore be an indication of the level of vibration expected in nearby structures. It has also been established that trucks and buses which travel at higher speeds provide higher induced-vibration levels than those traveling at lower speeds as indicated in Table 1.

Table 1: Comparison of vibration levels (mm/sec^2, *rms*) induced by a bus and a truck, to demonstrate the effect of different suspension systems at different speeds [1] .

	25 km/h		50km/h	
Location	**Bus**	**Truck**	**Bus**	**Truck**
Ground in front of house	20.5	19.9	64.5	33.2
External foundation wall	11.2	10.1	30.9	15.7
Mid point of floor in 1st storey	20.3	20.8	62.9	30.1
Mid point of floor in 2nd storey	35.0	37.3	96.2	46.7
Bus had air-bag suspension system; truck had multi-leaf steel spring suspension system.				

Vibrations in residential buildings, be they air-borne or ground-borne, are believed to be transmitted by particles in the medium (air particles or soil grains) of transmission. Thus, the velocity of the transmitting particles (peak particle velocity), frequency and amplitude are among the common measures used for assessing the extent of vibrations and any potential risk of damage to buildings. The resulting peak particle velocity of the soil grains depends on the soil type and its stratification. In addition, the characteristics of the soils particles (e.g., void ratio, porosity, etc.) at the time of transmission influence the vibrations induced by vehicular traffic.

The pavement type and structure of a roadway are additional factors that influence the vibration levels in buildings. It is thought that flexible pavements induce higher vibration levels in buildings than rigid pavements. In addition, the presence of irregularities (e.g., potholes, cracks and uneven manhole covers) induces higher dynamic loads on the pavement which in turn results in the generation of higher vibration levels in nearby structures. The distance of the roadway from the structure also influences the level and frequency of vibrations. Structures at a greater distance from the roadway often experience lower vibration levels than those closer.

The effects of these factors are generally interdependent. Due to the general preference for velocity as a measure of both annoyance and building damage, vibration criteria and some measured vibration data are sometimes presented in terms of overall vibration velocity levels. Common sources of vibration and the approximate maximum velocity levels are presented in Table 2.

Table 2: Common Vibration Sources and Levels [3]

Human/Structure Response	Velocity Level*	Typical Sources (50 ft from Source)
Threshold, Minor cosmetic damage; fragile buildings →	100VdB	← Blasting from construction projects
		← Bulldozers and other heavy tracked construction Equipment
Difficult with tasks such as reading a VDT screen →	90VdB	
		← Commuter rail, upper range
Residential annoyance, infrequent events (e.g., commuter train) →	80VdB	← Rapid transit, upper range
		← Commuter rail, typical
		← Bus or truck over bump
Residential annoyance, frequent events (e.g., rapid transit) →	70VdB	← Rapid transit, typical
Limit for vibration sensitive equipment. Approximate threshold for human perception of vibration. →		
	60 VdB	← Bus or truck, typical
		← Typical background vibration
	50VdB	

*RMS vibration velocity level in VdB relative to 10^{-6} inches/second

[3]Source: Transit Noise and Vibration Impact Assessment, FTA, DOT-T-95-16, April 1995

REVIEW OF DATA AND ANALYSES

- **Citizen Complaints**

The District of Columbia, over a five-year period, received complaints from residential homeowners and occupants about vibrations induced by vehicular traffic as well as rail and freight traffic. These complaints were documented and were provided to HUTRC for review. The complaints were analyzed in terms of the location and frequency of the vibrations reported.

To obtain a graphical view of the complaints by location, the addresses of the compliant sits were loaded into a Microsoft Access file which was then exported into ArcView. The resulting complaints by location are presented in Figure 1.

Clearly, from Figure 1, the complaints are widespread across the City. An appreciable number of these complaints, however, are found in areas in close proximity to railroads for freight and mass transit.

- **Boring and Soil Characteristics Data**

HUTRC received boring data provided by DDOT. However, the data received were limited to arterials (Bladensburg Road, New York Avenue, Florida Avenue, etc.) where the complaints are not primarily focused. In addition, the experiments to be conducted would largely be in residential neighborhoods and on residential streets.

DDOT also provided HUTRC with a subgrade soil characteristics report for the District of Columbia, which stems from work done by a consulting firm. The information provided in the report is a general review of soil information in connection with on-going efforts to refine the pavement management system of the District of Columbia. It provided a general soil survey map of DC which included seventeen detailed map sheets. The soil survey map divided the DC area into eleven (11) soil group. A detailed description of the soil classifications and their engineering properties were also provided in the report. The report also provided approximate soil strength values for general pavement design: California Bearing Ratio (CBR), resilient modulus (M_R) –flexible pavement design; modulus of subgrade reaction (k) – rigid pavement design.

CHOICE OF EXPERIMENTAL SITES

As shown in Figure 1, the vibration complaints are widespread across the City. Table 3 presents the City blocks selected as experimental sites for field investigate. In choosing the experimental sites the following criteria was used:

- freeways, arterials and collectors streets were avoided
- sites in close proximity to railroads were avoided
- each chosen site must have at least one complaint within the chosen block.

Table 3 presents the selected experimental sites, while Figure 2 shows their locations.

Table 3: Experimental Sites

Site	Location
1	300 -500 Block W Street, NW
2	1700 – 1900 Block Park Road, NW
3	1600 -1700 Trinidad Avenue
4	5700 -5800 14th Street, NW
5	5800 – 5900 Block 5th Street, NW
6	4719 - 4800 Chesapeake Street, NW
7	3760 – 3800 Benton Street, NW
8	300 - 500 Chestnut Street, NW
9	6412 -6500 Utah Avenue, NW
10	1601 - 1700 45th Street, NW
11	3200 -3300 Park Place, NW
12	2921 – 3000 Langston Place, SE
13	5201 – 5300 Chevy Chase Parkway
14	215 – 300 E Street, SE
15	3526 – 3600 S Street, NW
16	4820 – 4900 Glenbrook Road, NW

Detailed Site Information

The sites in Table 3 were chosen so that the risk of vibration coming from any source other than vehicular traffic would be avoided. Thus, no site located within close proximity to the Metro or other railway systems were chosen, and all arterial and collector streets were avoided. On visiting each site, a visual inspection of the entire block from which the complaint was received was carried out. The following information was collected at each site:

- Housing types (e.g., 1 storey, 2 storeys and 2 storeys with attic, etc.)
- Presence or absence of a basement
- Distance of house from the road
- Height from the road to the first floor
- Type of exterior structure of each building (e.g., brick, timber, etc.)
- Type of window (e.g., aluminum, wood, etc.)
- Retaining wall and height, if any.

Distances that could not be measured were estimated. The data collected for each experimental site are presented in the Appendix.

EXPERIMENTAL PLAN

Introduction

This experimental plan expands the investigation so that it would become more representative of the geographical area, taking into consideration the diversity of residential structures located on streets of different classification and traffic patterns. Based on the preliminary investigations discussed earlier and expressed at meetings with DDOT officials, HUTRC was asked to expand the research from two (2) to sixteen (16) sites and to explore ways for obtaining data that were determined to be unavailable from DDOT. In the first phase of this research HUTRC collected available data from DDOT. This data included reports of vibration from citizens, soil borings, railroad and road maps. HUTRC further visited the complaint sites to assess appropriateness for inclusion for further investigation. HUTRC had to eliminate sites that are possibly being vibrated by non-street traffic. Sites that are located close to or above rail lines were eliminated. The following city blocks are selected for further investigation:

A general description of sixteen sites chosen is presented in Table 2. The remaining sections description of the sixteen sites chosen is presented in Table 2. The remaining sections of this report present and discuss the various tasks and data collection and reduction association with the experiments of the expanded investigation.

Hypotheses:

The following null hypotheses relate to traffic-induced vibrations in residential houses of Washington DC:

1. Traffic-induced vibrations (ground-borne) do not exceed tolerable limits for residential structures.

2. Traffic-induced vibrations are primarily caused by heavy vehicles such as trucks and buses.

3. For any heavy vehicle type, the magnitude of the ground-borne vibration is higher that the air-borne vibration.

4. The ground-borne vibration level is correlated with one or more of the following factors:
   (a) pavement condition index (PCI)
   (b) pavement structural condition
   (c) geotechnical condition below the pavement and area.
   (d) type of structure of houses : brick or frame
   (e) international roughness index (IRI)

5. The average vibration levels of frame structures and brick structures are equal.

Description of Tasks and Data Collection

Task 1: Selection of Residential Units for Observation Stations

The field observations conducted in Phase 1 provided information on the various types of dwelling structures that occupy both sides of each selected city block. Two frame and two masonry structures will be selected for referencing the various pavement and geotechnical data to be collected on each of the selected city blocks. Each of the selected dwellings will become an observation station with a street address. Sixty-four (64) observation stations are planned for the expanded investigation; thirty-two (32) frame structures and thirty-two (32) masonry structures. Although, the research team will do its best to identify a typical two-story structure that is representative of all the selected city blocks, variations in the topography surrounding of each unit will be recorded. For example, some houses may be built into an embankment or on a side-hill to obtain a sub-surface basement, others may have basement ceilings that are close to curb elevation; and yet, floors of some houses could be above curb elevation. The research team will estimate the elevations of floors above the curb and record the topography associated with each of the observation station since traffic-induced vibration may affect each differently. The outcome of this task will be sixty-four observation stations that are determined to be similar in the number of floors, and their placement on the city block (vertical and horizontal). Care will be taken in selecting only observation stations that are not likely to receive vibration from above-ground and underground rail systems.

Task 2: Field Data Collection

A number of factors could contribute to conditions for building vibration. Among them are vehicle type and traffic volume, traffic speed, pavement type and condition, pavement design, type of sub-surface soil, type of residential structure, and distance from the traffic lane. Some of this field information (that involves little risk to the health and safety of the research team) will be collected by the University. Data collection that requires the use of industrial equipment ground penetrating radar, for example – will be undertaken by a contractor. The data collection effort is discussed below.

<u>2.1 Traffic Volume Data:</u> Two ten-hour traffic volume counts will be conducted on each of the sixteen city blocks. Each city block will be counted on a Wednesday and on a Friday. The counts will provide traffic volume (vehicles per hour) peaking characteristics and vehicle characteristics. HUTRC will use its judgment regarding the use of automated equipment or manual inventory. Manual counts have the advantage of clearly identifying heavy vehicles by type (local bus, school bus, dump truck, semi-trailer, etc.), but may not be suitable for high volume facilities. Where machines are used, one-hour manual classification counts will also be done so that sub-classification of heavy vehicles can be determined. The University will purchase or rent two automatic traffic counting machines with the appropriate paraphernalia for securing them in the field.

<u>2.2 Traffic Speed Data:</u> Speeding could be a contributing factor to vibration when pavement surface conditions are not ideal. HUTRC will conduct speed observations at

each of the sixteen city blocks, using its radar speed detection equipment. The standard speed data analyses will be performed to estimate average speed, ten mile per hour pace, eighty-fifth percentile speed, and the extent to which the posted speed of each block is being violated.

2.3 Ground Penetrating Radar (GPR) Data: Data on the longitudinal profile of the various layers of pavement and subgrade of the various sites are not available in DDOT records. Past DDOT GPR observations focused on the higher volume collectors and arterial streets. GPR data are essential for relating subsurface conditions to the propagation of vibration. Further GPR will provide pavement subsurface thicknesses for each of the 16 city blocks. The GPR data collection will be provided by a contractor who is experienced in making GPR observations in the City. The contractor will calibrate the GPR equipment prior to data collection. Measurements will be taken at 1-ft intervals, in both directions of travel lanes, and with automatic recording of data. The contractor will be responsible for appropriate temporary traffic control during the collection of GPR data. The production of this effort will be the longitudinal layer thickness within 18-24 inches below the surface of the pavement for each of the 16 city blocks.

2.4 Visual Pavement Surveys: As indicated earlier pavement texture and general structural condition can contribute to traffic-induced vibration. Rough and uneven pavement surface and structural cracks in upper layers are conditions that are often the result of poor pavement design that is further stressed by heavy vehicles. Structural cracks are often not easily detected by the untrained eye. The University will train and employ students in conducting a pavement condition survey on each of the 16 sites. The survey will cover the entirety of each of the selected city block. Pavement condition survey forms will be used by the students who will also calculate the Pavement Condition Index (PCI) for each site. In order to minimize personal errors in rating pavement conditions, HUTRC plans to use the same students to cover all 16 sites. Some of our graduate students have taken courses in pavement design and pavement management and could apply themselves in the visual pavement condition surveys.

2.5 Pavement Ride Quality: The ride quality of the pavements takes into consideration the composite behavior of pavement profile vehicle suspension systems. The better the ride quality of the integrated systems, the lower the acceleration forces that cause vibration to travel beyond the vehicle-pavement interaction surfaces toward adjacent properties. Collection of ride quality data will be done with specialized ride quality equipment that is usually rented. However, HUTRC will rely on a contractor for renting equipment and conducting the ride quality surveys. The data recordation will be automatic and will include international roughness index (IRI) measurements for various intervals, and in both directions, along each city block. The composite IRI for each city block will be determined. Use of a contractor for collecting the raw data will avoid having students use complicate equipment attached to vehicles in the field. The contractor will be responsible for all traffic safety measures during the collection of the data.

2.6 Pavement Structure Evaluation: Weak pavement can contribute to the propagation of vibration. Weak spots lead to depression and cracks in pavement layers that are not always detectable by visual observation of the surface. The single factor that indicates the strength of the various layers of pavement is the resilient modulus (M_R). The higher the (M_R) of the individual layers of the composite pavement, the lower the tendency to transmit vibration waves. The University will utilize a contractor to collect structural condition data on each of the 16 city blocks. Observations will be made in both directions. The falling weight deflectometer (FWD) readings will be taken in accord with AHSHTO standards, at 50-ft spacing. The contractor will provide the raw deflection detected sub-surface voids, as well as the computed moduli, by layer, in comparison with a rationally accepted standard. As with all observations on the travel lanes, the contractor will be responsible for traffic safety and control during data collection.

2.7 Geotechnical Profile of City Blocks: Two test borings will be taken on each of the sixteen city blocks to determine the actual thickness and properties of the soil near the four structures that serves as observation stations. Up to 32 borings are expected depending on the spatial relationship between the selected observation stations. The boring are to provide information to deduce pavement layer thickness, strength, consistency, and standard soil properties down to a depth of 7ft below the surface of the pavement. The boring data will also be used to complement the work proposed in Subtask 2.3 that deals with GPR measurements.

2.8 Vibration Measurement at Observation Stations: The vibration generated by vehicles is likely to be propagated through the air as sound and through the ground as seismic waves. Observation of vibration is necessary in order to confirm which type of vibration is the dominant nuisance factor. Ground-borne vibrations will be measured in the vicinity of each of the four observation stations on each of the selected city block. Accelerometer readings will be taken at the building line, as close as possible to the foundation walls. The peak acceleration, velocity, and frequency and the time of the vibration will be measured. All measurement must be coordinated with identified heavy vehicles as well as with FWD activity described in Sub-task 2.6.

Air-borne vibration measurements will be taken at the same observation stations, in the same manner and locations as the ground-borne vibration. Noise measuring instruments appropriate for measuring noise environment noise levels in or near houses will be used. The peak particle velocity, frequency and time of peak of the vibration will be measured and recorded. The peak vector sum and peak sound pressure level will be calculated from the recorded observations.

Task 3: Data Reduction and Analysis

The various data collection exercises described above will yield data that would require some analysis to arrive at values that will be used in the statistical analyses for confirming or refuting the stated hypotheses. For each observation station of each city block, the following data will be complied:

- Traffic volume (AADT)
- Percent of Heavy Vehicles

- Predominant Heavy Vehicle Type
- PCI
- IRI
- Resilient Moduli (Composite) of Existing Pavement
- Desirable Resilient Moduli (Composite) for Soil Condition
- Air-borne Vibration Building Line
- Ground-borne Vibration at Building Line
- Soil Classification
- Thickness of existing pavement layers

The statistical analysis will involve testing the equality of means and determining the level of correlation, if any, between vibration levels and selected factors. This effort will quantify and compare observed means against standards and against calculated values. Some engineering comparison will also be done in order assess the adequacy in the design of the existing pavements. For example, the composite resilient moduli deduced from field data will be compared with the moduli required for soil and traffic conditions. The engineering analyses will also provide some insight on possible solutions for mitigating the magnitude of vibration waves that travel into residential properties. The fundamental outcome of the analyses is a determination as to whether traffic-induced vibration is above the threshold values for residential units and the characterization of the factors associated with the vibration.

Task 4: Draft Final Report

The entire research effort will be compiled into a Draft Final Report and submitted to DDOT for review and comment. The outline of this report will be submitted to DDOT for review and approval prior to the submittal of the report itself. DDOT will provide its written comments and recommendations within thirty (30) days after receiving this report from the University.

Task 5: Final Report

After receiving all comments from DDOT, the University will proceed to develop the Final Report that would incorporate the recommendations of DDOT. The University will submit the Final Report as an electronic file and twenty copies.

PROJECT MANAGEMENT

Dr. Imram Syed will be the principal investigator while Dr. Errol C. Noel will serve as the associate principal investigator. Mr. Stephen Arhin will serve as the project manager with the support of HUTRC staff. A statistician from the Mathematics Department at Howard University will be appointed to help with the data analyses and interpretations. Two (2) graduate students will be recruited as Research Assistants on the basis of their demonstrated preparedness for research on the subject matter. Thomas L. Brown Associates (TLB) will be hired as the contractor to lead the field data collection and reduction due to to its proven expertise in the subject matter, and its familiarity with DOT protocol for geotechnical investigations on city streets.

Table 4: Distribution of Labor by Personnel

TASK	PERSONNEL						TOTAL
	P.I	Associate P.I.	Project Manager	Contractor	Statistician	Students	
1	120	30	20	80	10	80	**260**
2	150	50	30	360	60	240	**650**
3	160	50	20	100	160	180	**490**
4	190	80	40	120	60	150	**490**
5	80	60	20	60	30	80	**250**
TOTAL	**700**	**270**	**130**	**720**	**320**	**730**	**2,140**

BUDGET

The following budget is based on performance period of 18 months. This duration will enable students and faculty meet other obligations while satisfying the objectives of the experiment.

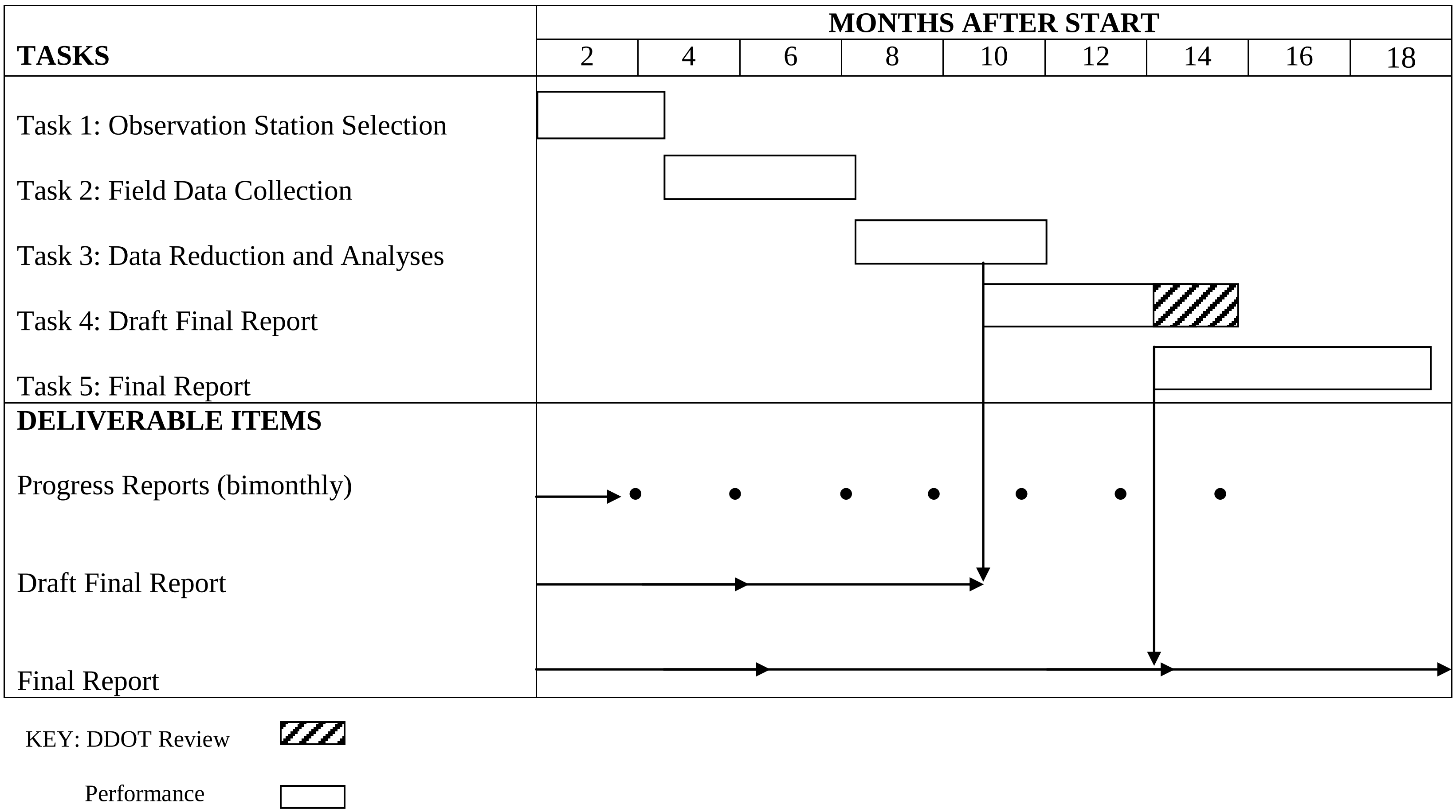
Table 5: Budget

PERSONNEL	Hourly Rate/Misc.	Total Hours	Amount
Prncipal Investigator	$50.00	700	$35,000.00
Associate P.I.	$50.00	270	$13,500.00
Project manager	$25.00	130	$3,250.00
Statistician	$40.00	320	$12,800.00
	Subtotal		**$64,550.00**
	Faculty Benefit @19%		$12,264.50
	Subtotal		**$76,814.50**
	Supplies		$5,000.00
	Subtotal		**$81,814.50**
	Indirect Cost @51%		$41,725.40
	Subtotal		**$123,539.90**
Research Assistants	$15.00	730	$10,950.00
Sub Grand Total			**$134,489.90**
Contractor	$150.00	720	$108,000.00
Equipment Rentals	$120.00	120	$14,400.00
GRAND TOTAL			**$256,889.90**

PROJECT SCHEDULE

The proposed duration of this project is 18 months from notice to proceed. This program involves the summer months of 2003, with an assumed start date of January 2003. Figure 3 presents the profile schedule. Bimonthly progress reports will enable DDOT to track progress. Scheduled deliverable items are the Draft Final Report and the Final Report.

Figure 3: Project Schedule



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2. "Guide to the Evaluation of Human Exposure to Vibration in Buildings". American National Standard.

3. "Transit Noise and Vibration Impact Assessment," FTA, DOT –T-95-16, April 1995.

4. Hunaidi, O., Rainer, J.H. and Pernica, G. "Measurement and analysis of traffic-induced vibrations." Proceedings of the 2nd International Symposium on Transport Noise and Vibration, St. Petersburg, Russia, 1994, pp. 103-108.

APPENDIX

A detailed location map of each site is presented in this section. Distances that could not be measured were estimated. The sites in Table 3 were chosen so that the risk of vibration coming from any source other than vehicular traffic would be avoided. The following information was collected at each site and are presented in the following tables:

- Housing types (e.g., 1 storey, 2 storeys and 2 storeys with attic, etc.)
- Presence or absence of a basement
- Distance of house from the road
- Height from the road to the first floor
- Type of exterior structure of each building (e.g., brick, timber, etc.)
- Type of window (e.g., aluminum, wood, etc.)
- Retaining wall and height, if any.

A brief description of each site is given below:

Site 1 (300 W Street, NW)

W street runs in the East-West direction. It is located approximately 500 ft from Georgia Avenue and crosses it within the vicinity of a Central Business District (CBD). The nearest mass transit rail line is located at about 5000 ft from this site.

Site 2 (1700-1900 Block Park Rd., NW)

This section of Park Road is mainly residential and runs in the East-West Direction. The nearest mass transit rail line is located at about 2000 ft from this site. The area covered in this research ranged between 17th St. and 19th St.

Site 3 (1620 Trinidad Avenue, NE)

Trinidad avenue runs in a north-south direction and is parallel to Bladensburg Road but spans a distance of 400 ft between them. The nearest rail line is located at about 5500 ft from this site.

Site 4 (5703 14th St., NW)

Located at about 260 ft west of 16th Street, 14th Street runs in a North South Direction. The specific area of study was located between Montague St. and Madison St. The routes of mass transit buses S2 and No. 54 ply along this section of 14th Street. The nearest rail line is located at about 6500 ft from this site.

Site 5 (5800 Block 5th St., NW)

This block is positioned between Oglethorpe and Nicholson St. and runs in a North-South direction. Metro bus No. 62 runs along this route. The closest arterial road is Kansas Avenue, which is about 600 ft from this site.

Site 6 (4719 Chesapeake St., NW)

Chesapeake St. runs in the East-West Direction. It is located approximately 500 ft from Western Avenue which is the closest arterial road within the environs of this site. The site is located between Tennyson St. and Barnaby St.

Site 7 (3760 Benton St., NW)

Benton Street runs in the East-West direction in a middle class residential neighborhood. The 3700 block is bounded by Huidekopper St. to the west and 38th street to the east. Mass transit bus No. D2 bus passes along Benton St. in the direction towards Wisconsin Avenue, which is located about 250 ft from this site.

Site 8 (3300 Chestnut St. NW)

Chestnut St. runs in the East-West direction. This site is located at about 8500 ft from the nearest mass transit rail line .The closest arterial road is Western Avenue which is about 750 ft west of the chosen site. The 3300 block of Chestnut Street is bounded by Oregon Ave. and 32nd St.

Site 9 (6412 Utah Avenue NW)

Located at about 450 ft from Western Ave, Utah Avenue runs in a North-South direction. The block along which the complaint came from is frequented by the city's No. M4 bus. At a distance of about 7800 ft west of this site is the closest mass transit rail line.

Site 10 (1601 45th Street NW)

45th Street runs in a North-South direction and intersects Reservoir Road on the North side at a distance of about 250 ft. Rail lines for mass transit and freight are not located in the immediate vicinity of this site.

Site 11 (3200 Park Place NW)

The 3200 block of Park Place can be found at approximately 450 ft east of Georgia Avenue. The road runs in the East-West direction and is relatively close to a variety of businesses.

Site 12 (2921 Langston Place SE)

This block is positioned between Hartford and Reynolds St. and runs in a North-South direction. The closest arterial road is the Suitland Parkway, which is at a distance of about 375 ft from this site.

Site 13 (5201 Chevy Chase Parkway)

The Chevy Chase Parkway runs in a North East direction. This site is location at approximately 150 ft east of Chevy Chase Parkway. Rail lines for mass transit/freight were located at about 3600 ft from this site.

Site 14 (215 E St. SE)

E St runs in the East-West direction. Rail lines for mass transit and freight are not located in the immediate vicinity of this site.

Site 15 (3526 S St. NW)

Running in the East-West direction and bounded by 35^{th} St. to the East and 36^{th} St. to the West, the 3500 block of S Street could be classified as running through middle-income housing area. It is located about 300 ft east of Wisconsin Avenue.

Site 16 (4820 Glenbrook NW)

The 4800 Block of Glenbrook runs in the East-West direction. It lies 700 ft south of the intersection of Nebraska and Massachusetts Avenue and approximately 10,000 ft from rail lines for mass transit.