METHOD AND GUIDLINES FOR THE STRUCTURAL DESIGN OF CONCRETE BLOCK PAVEMENTS IN URBAN STREETS

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ABSTRACT

Recently, the Israel Ministry of Housing and Construction has issued the third volume of its Guidelines for the Design of Urban Streets. This volume is dedicated to "Pavement Structures of Roads, Aprons and Sidewalks". Two types of pavement are included: Flexible asphaltic pavements and Concrete Block Pavements (CBP). For each one, the guidelines provides a complete system of design methodology which enable the designer to consider systematically all the factors involved in the design process up to the mechanistic determination of the optimal and economical pavement structure with the proper materials for each layer. This paper describes the method and guidelines for the structural design of Concrete Block Pavements in Urban Streets, with an emphasis on the following factors:

Traffic Variables: Partition to seven traffic categories from Occasional Traffic up to Very Heavy Traffic. These categories are matched with both the type of street (local, collector, arterial, etc.) and the number of adjacent dwelling units served. The traffic categories are finally translated to a design number of 18 kips. Equivalent Single Axle Load (ESAL) for the mechanistic analysis. Special consideration is given to the destructive traffic loading occur during the construction phase of new neighborhoods.

Subgrade Investigation and Material Survey: The detailed guidelines instruct the engineer with the importance and details of the geotechnical investigation and surveys that should provide the reliable and economical design parameters related to the subgrade and pavement materials. A set of action list and guidelines are given for each phase of the investigation (general, preliminary, and detailed subgrade investigation). Instructions are given for the analysis of field and laboratory test results towards the quantitative determination of the design parameters (CBR, density, swell and heave, etc.).

Earthwork and Slopes: The detailed guidelines also deal with stability of slopes in cut and fill during earthworks and under long-term service. Recommendation of slope angles and safety factors in cut and fill for the different soil types are given.

Concrete Block Pavement Design: As a well-established technology, CBP are quite popular in urban areas in the country. The detailed guidelines back-up the attractive CBP alternative with the aid of the proper design tools: Typical CBP structures, paver laying patterns, paver shape selection, side confinement, paver quality and surface characteristics, permeability and drainage, behavior in steep slopes, etc. Two sets of pavement design curves are provided for the determination of the total pavement thickness and the thickness of each layer and the pavers. This determination is based on the traffic category and the value of design subgrade CBR as input parameters.

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1. INTRODUCTION

The Israel Ministry of Housing and Construction (MHC) had issued in 2000 the third volume of its Guidelines for the Design of Urban Streets. Following the first two volumes that deal with the geometric design of urban streets and intersections, this volume is dedicated to "Pavement Structures of Roads, Aprons and Sidewalks". Two types of pavement are included: Flexible asphaltic pavements and Concrete Block Pavements (CBP). For each one, the guidelines provides a complete system of design methodology which enable the designer to consider systematically all the factors involved in the design process up to the mechanistic determination of the optimal and economical pavement structure with the proper materials for each layer. This paper describes the method and guidelines for the structural design of Concrete Block Pavements in Urban Streets, with an emphasis several key factors that will be described in details.

The design methodology is generally based on two research efforts financed by the Israel Ministry of Housing and Construction and the Public Works Department (PWD). The first one deals with a special characterization of traffic variables to fit the urban streets and neighborhoods (Uzan and Gur, 1989). The second one presents the mechanistic structural design of the pavement using the extended CBR method for determining the total thickness of the pavement, and the fatigue criteria for determining the quality and thickness of the pavement layers (Uzan 1996). It is also based on accumulated local experience, as expressed by Livneh, Ishai and Uzan (1979), Livneh, Ishai and Nesichi (1985), and by Divinsky, Livneh and Nesichi (1998). The design methodology and its related guidelines were compiled for the urban transportation infrastructure designers in a practical folder accompanied by a user-friendly computer aided program (Ishai, Livneh, Craus and Ruhm, 2000).

1.1 Traffic Variables

The development of traffic analysis for pavement design in urban environment resulted with unique method that possesses the following advantages:

- The method does not rely on traffic counts and surveys for a specific street and therefore it especially suitable for areas of initial development.
- The method enables maximum dependence on specific factors that influence the structural pavement design, such as: paving timing, waste disposal system, planning of bus routes, etc.
- The method enables the realization the saving caused by the modern urban development that restrains and even prevents through traffic in activity zones.
- The method is economic and can be used for traffic predictions under wide range of pavement types and traffic loadings.

The adaptation of traffic characteristics and variables for plugging in the pavement design process requires the consideration of the following factors: axle loads and distribution; configuration of axles and wheels; tire pressure; volume and time distribution of tracks and other heavy vehicles; traffic speed; lateral distribution of vehicle movement; loading type (static, dynamic, breaking, acceleration, etc.). These factors were analyzed and adapted to the urban traffic by using the street classification that govern the geometric design.

The streets in the urban area are classified to four groups (as also demonstrated in Figure 1):

- Urban Freeway.
- Arterial Street.
- Collector Street.
- Local Street.

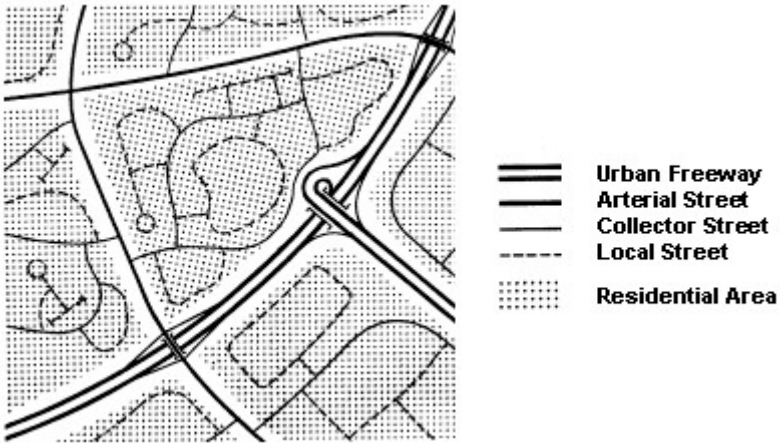


Figure 1. Classification of Streets in an Urban Area.

The analysis of traffic loading factors for pavement design was expressed by the partition of traffic loading in to seven categories:

- Occasional Traffic.
- Very Light Traffic.
- Light Traffic.
- Medium-Light Traffic.
- Medium-Heavy Traffic.
- Heavy Traffic.
- Very Heavy Traffic.

The adaptation and combination of these categories for the street classification are as follows:

1.2 For Local Streets:
Occasional Traffic (1) – Traffic serving up to 150 dwelling units.
Very Light Traffic (2) – Traffic serving 150-450 dwelling units, where a local shopping center exists in the neighborhood.
Light Traffic (3) – Traffic serving 450-1,500 dwelling units, where a supermarket exists in the neighborhood.

1.3 For Collector Street:
Medium-Light Traffic (4) – traffic, including buses, serving up to 2000 dwelling units, where one system of supermarket and local shopping center exist in the neighborhood.
Medium-Heavy Traffic (5) – Traffic, including one bus rout, serving 2,000-15,000 dwelling units, where one system of supermarket and local shopping center exist in the neighborhood.

1.4 For Arterial Street:
Traffic loading for this street classification is calculated using the knowledge of the entire traffic volume for the design period (including private cars) and the percentage of trucks and buses. Existing models are used to calculate the accumulative number of Equivalent Standard Axle Load (ESAL) for design (Ishai, Livneh, Craus and Ruhm, 2000). For this street classification the *Heavy Traffic (6)* and the *Very Heavy Traffic (7)* categories are defined, where the *Medium-Heavy Traffic (5)* is considered as the minimum. The accumulative number of ESAL's for each traffic category, according to AASHTO, are presented in Table 1.

Table 1. Accumulative number of 18,000 lbs. ESAL's for each traffic category according to AASHTO (1993).

Traffic Category	Category Number	Accumulative Number of 18,000 lbs. ESAL's
Occasional Traffic	1	$0.0x10^4 – 3.8x10^4$
Very Light Traffic	2	$3.8x10^4 – 1.0x10^5$
Light Traffic	3	$1.0x10^5 – 3.6x10^5$
Medium-Light Traffic	4	$3.6x10^5 – 1.2x10^6$
Medium-Heavy Traffic	5	$1.2x10^6 – 5.5x10^6$
Heavy Traffic	6	$5.5x10^6 – 1.5x10^7$
Very Heavy Traffic	7	$1.5x10^7 – 8.0x10^7$

1.5 For Urban Freeway

The traffic analysis is done similar to rural highways and roads using valid models for conversion of traffic to accumulative number of ESAL's.

In addition to the traffic flow in the streets, the design guidelines specifies the methods for treating static loadings in parking areas, traffic in intersections, and the special heavy traffic that passes during the construction phase of new neighborhoods, as will be presented later on. The integration of the traffic factors in the pavement design process is done by plugging the proper traffic category within the design curves or the computer program, as will be discussed in the following section:

2. PAVEMENT DESIGN METHOD

The pavement design method for Concrete Block Pavements (CBP) is mainly based on local experience and intensive research involving the Ministry of Housing and Construction, the Public Works Department and the Technion – Israel institute of Technology. As initially reported by Livneh and Ishai (1988), the development of the CBP design method is generally derived from that of Flexible Pavements, where the flexible designed pavement structure is converted to a CBP structure using mechanistic layer equivalency factors.

The mechanistic structural design of the flexible asphaltic pavement used by the Public Works Department (PWD) is based on two separate systems characterizing the failure mechanism of pavements. The first one for predicting the fatigue of the top asphalt layers, and the second one for predicting the rutting of the subgrade. These two systems are derived from the semi-rational design methods. In these methods the pavement structure is modeled as a multi-layer system (usually composed of linear elastic materials) that should withstand the critical strains induced by the traffic. These critical strains are connected with the following two failure mechanisms: (a) the tension strain at the bottom of the asphaltic layers which enhance their fatigue deterioration, and (b) the compression strain at subgrade surface which induce rutting at the bottom of the pavement. This mechanistic model is described in Figure 2.

In the updated PWD design method the total thickness of the pavement can be calculated by the following equation:

$$H = 15.021\ (\log ESAL_P)^{1.143}\ (CBR)^{-0.556} \qquad (1)$$

Where:

H is the total thickness of the flexible pavement in centimeter

CBR is the design CBR value of the subgade in percent

$ESAL_P$ is accumulative number of ESAL's for design according to PWD

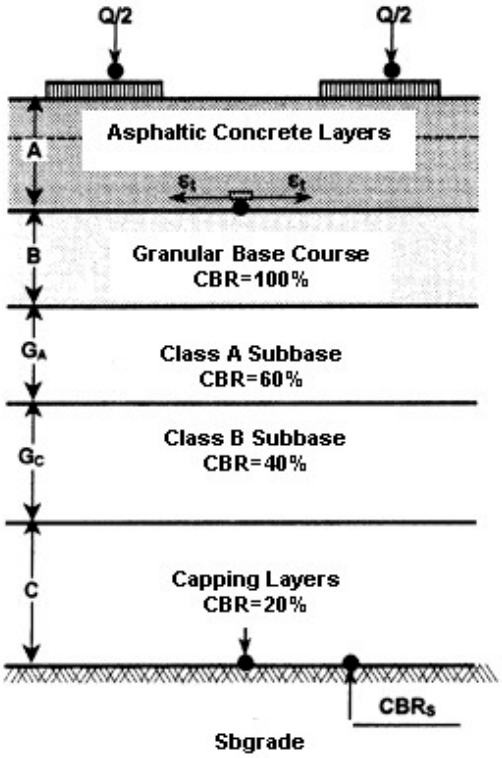


Figure 2. The PWD model for the mechanistic structural design of the flexible asphaltic pavement.

The equivalent accumulative number of ESAL's for design according to AASHTO ($ESAL_A$) can be calculated from the PWD values, or vice versa, using Table 2, as follows:

Table 2. The Ratio Between $ESAL_P$ and $ESAL_A$.

Subgrade CBR (%)	Traffic Category and Values of $ESAL_A$						
	Occasional (1) $3.8x10^4$	Very Light (2) $1.0x10^5$	Light (3) $3.6x10^5$	Medium-Light (4) $1.2x10^6$	Medium-Heavy (5) $5.5x10^6$	Heavy (6) $1.5x10^7$	Very Heavy (7) $8.0x10^7$
2	1.18	1.30	1.50	1.66	2.01	4.91	9.97
4	1.15	1.23	1.37	1.62	1.80	3.54	6.42
6	1.14	1.20	1.32	1.62	1.73	2.92	4.96
8	1.14	1.19	1.30	1.62	1.69	2.55	4.13
10	1.13	1.18	1.28	1.62	1.67	2.29	3.59

Table 3. Layer Equivalency Factors Related to the Thickness of Class A Dense Graded Asphaltic Concrete.

Layer and Material	Thickness of the layer Equivalent to 1.0 cm of Asphaltic Concrete
Concrete Pavers	0.8
Class A Dense Graded Asphaltic Concrete	1.0
Cement Stabilized Base Course	1.2
Cement Modified Base Course	1.3
Non-Stabilized Base Course	1.5
Class A Subbase Course	2.0
Class B Subbase Course	2.5
Bedding Sand	∞*

* The bedding sand has no structural value

The "cement stabilized base course" contains 4%-6% Portland Cement, and the "cement modified base course" contains 2%-3% Portland Cement. It should be also mentioned that in traffic categories 1-3, a Class B Subbase material could be used.

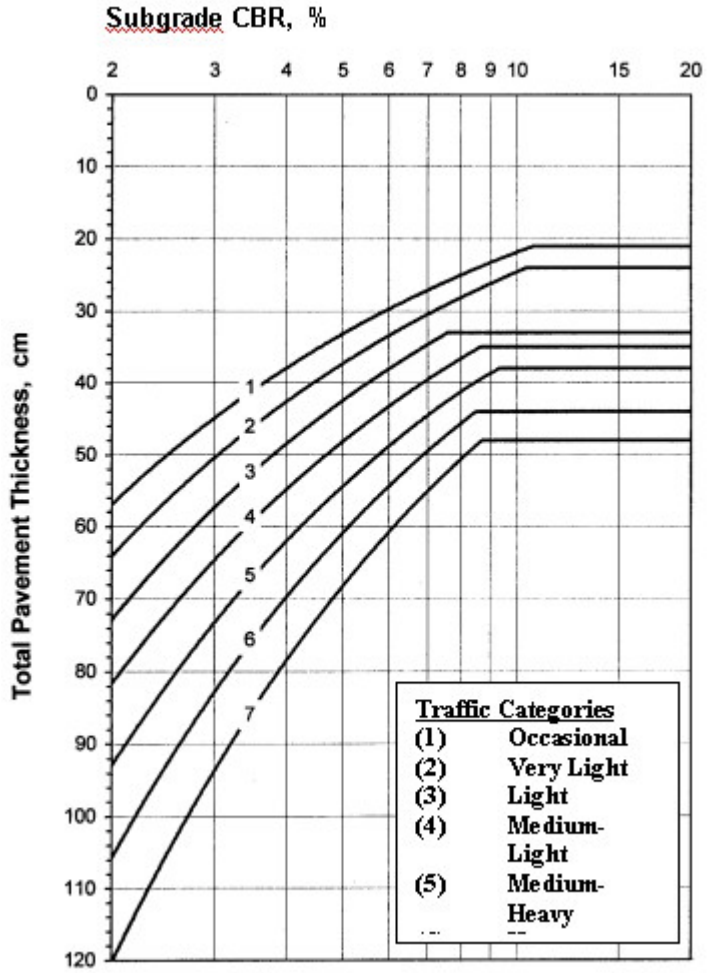


Figure 3. Design curves for Concrete Block Pavements – Total pavement thickness.

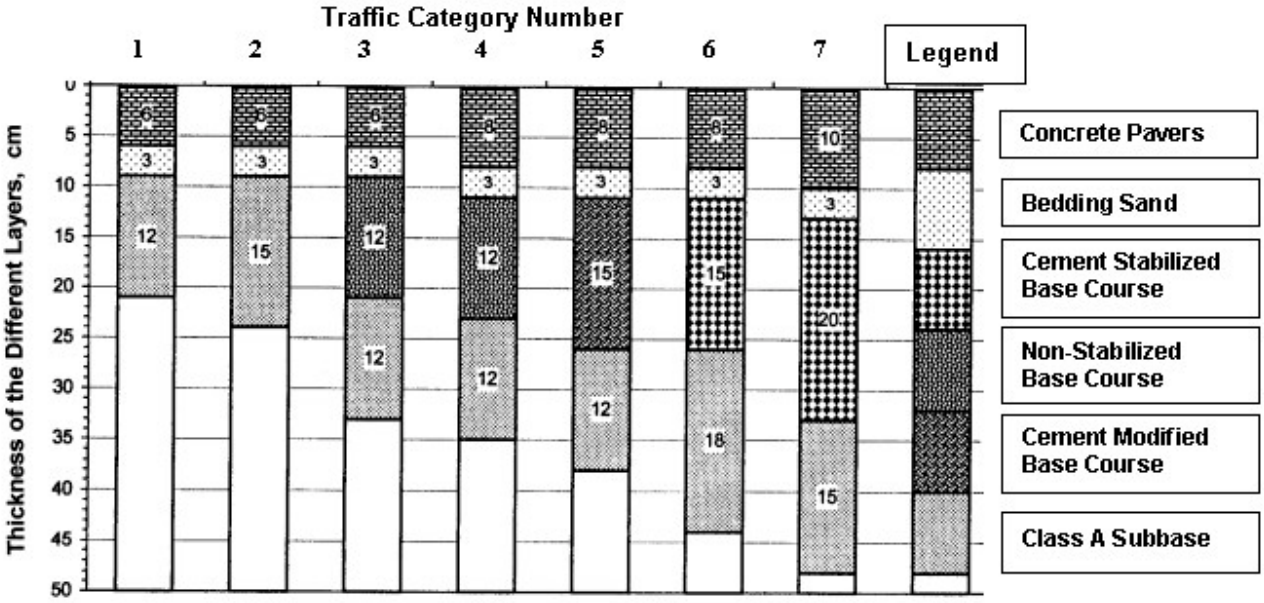


Figure 4. Design curves for Concrete Block Pavements - Thickness of the different upper layers (the remain bottom layers are of Class B Subbaes).

3. CONCRETE BLOCK PAVEMENT CHARACTERISTICS

In the design guidelines for "Pavement Structures of Roads, Aprons and Sidewalks" issued by the Israel Ministry of Housing and Construction (MHC), several recommendations and guidelines are also given for different characteristics of the Concrete Block Pavement. Among them are:

3.1 Traffic During Construction

Many streets in new urban neighborhoods are paved prior to the erection and construction of the buildings and other facilities. In this case the finished pavement is exposed to very intensive heavy and detrimental traffic loadings. The design guidelines presents a method for estimating the traffic during construction and also recommend to perform a "stage construction" under which a temporary thin asphalt layer is paved on top of the base course to serve the construction period. At the end of the of the construction period the bedding sand and the top pavers are laid prior to the inhabitation.

3.2 Optimal Choice of Pavers Shape & Laying Patterns

The design guidelines direct the designer for the optimal selection of Pavers Shape & Laying Patterns. Due to the international controversy in this respect, a distinction is made between "structural" and "functional" aspects. The structural aspects calls for interlocking paver shapes and bi-directional laying patterns, while the functional aspects permits aesthetics considerations and "self locating" laying techniques. An emphasis is given to the control of optimal joint thickness between the blocks.

3.3 Drainage and Sensitive Subgrades

The rapid surface drainage of the concrete block pavement is of utmost importance due to the very pervious character of the CBP surface in early service. Therefore, the guidelines call for higher minimum longitudinal and transverse slopes than that of flexible pavements. As a function of subgrade soil type, underground drainage is specified for consideration. Specific solutions are recommended for expansive and collapsible soils, such as impervious membrane, soil replacement, soil stabilization, etc.

3.4 Concrete Block Pavements in Steep Slopes

One of the advantages of CBP, is the possibility to apply them in steep roads (larger then 7%). However, as specified in the guidelines, this application requires some additional precautions related to the following aspects: assurance of fast surface drainage; use of special pavers shapes; use of thicker pavers; bi-directional angle laying; uphill laying sequence; use of drainage pavement layers; stabilization of joint sand; use of geotextiles in the bottom of the bedding sand; use of coarser bedding sand; and installation of underground supporting elements (see also Ishai et.al 1992, 1999).

3.5 Maintenance and Reuse of Pavers

Another major advantage of the concrete block pavement is the relative simplicity of its maintenance and the possibility of reusing paving block after treatment of lower layers or for another paving use. The guidelines, together with the Israeli Standard IS 1571 (1998), provide a set of recommendation for identifying and treatment of typical CBP distresses and the criteria for reusing pavers.

3.6 Concrete Block Pavement Structure for Sidewalks

In addition to the pavement design curves for urban streets, the design guidelines also provide simple design recommendations for concrete block pavement structures for sidewalks. This can be summarized in Table 4, as follows:

Table 4. Concrete Block Pavement Structure for Sidewalks.

Layer Detail		Layer Thickness (cm)
Concrete Pavers		6.0
Bedding Sand		3.0
Thickness of Class A Subbase for the Given Subgrade CBR Value	3-5%	20.0
	6-8%	15.0
	>8%	12.0

3.7 Subgrade Investigation and Material Survey

As general for both CBP and flexible pavements, the guidelines instruct the engineer with the importance and details of the geotechnical investigation and surveys that should provide the reliable and economical design parameters related to the subgrade and pavement materials. A set of action list and guidelines are given for each phase of the investigation (general, preliminary, and detailed subgrade investigation). Instructions are given for the analysis of field and laboratory test results towards the quantitative determination of the design parameters (CBR, density, swell and heave, etc.).

3.8 Earthwork and Slopes

In similar manner, the guidelines also deal with stability of slopes in cut and fill during earthworks and under long-term service. Recommendation of slope angles and safety factors in cut and fill for the different soil types are given.

4. SUMMARY

This paper presented the method and guidelines for the structural design of Concrete Block Pavements in Urban Streets as recently developed for, and issued by, the Israel Ministry of Housing and Construction. Two types of pavement are included: Flexible asphaltic pavements and Concrete Block Pavements (CBP). For each one, the guidelines provides a complete system of design methodology which enable the designer to consider systematically all the factors involved in the structural design process up to the mechanistic determination of the optimal and economical pavement structure with the proper materials for each layer. For the Concrete Block Pavement, the pavement designer is provided with a special method to characterize the traffic in urban zones, and a simple design curves for dimensioning the total pavement thickness and the thickness of the various layers. The paper also summarizes the specific concrete block pavement characteristics that should be considered and involved in the design process. This design system is widely and successfully operative in Israel during the last three years.

5. REFERENCES

American Association of State highway and Transportation Officials – AASHTO (1993) “Guide for the Design of pavement Structures”.

Divinsky, M., Livneh, M. and Nesichi, S. (1998) “Development of General Regression Equations Adequate for the Flexible Pavement Design Method of the Public Works Department” Research Report No.98-258, Transportation Research Institute, Technion.

Ishai, I., Dalin, J.S., & Rubin, H. (1992) "The Stability of Steep Block Pavements Under High-Velocity Water Flow Conditions." Proc. of the 4th Int. Conference on Concrete Block Pavements, Vol. 1, pp. 117-132.

Ishai, I., Dalin, J.S., and Rubin, H., (1999) “The Resistance of Steep Concrete Block Pavements to High-Velocity Water Flow,” Transportation Research Record No. 1684, Journal of the Transportation Research Board, pp. 118-127

Ishai, I., Livneh, M., Craus, j., and Ruhm, C. (2000) “Guidelines for the Design of Urban Streets - Pavement Structures of Roads, Aprons and Sidewalks” Issued by the Israel Ministry of Housing and Construction.

Israeli Standrds Institute (1998) “Concrete Block Pavements” Israel Standard No. IS 1571.

Livneh, M., Ishai, I., & Uzan, J. (1979) "Chapters in the Design of Flexible Pavements" Publication No. 79-24, Transportation Research Institute, Technion.

Livneh, M., Ishai, I., & Nesichi, S. (1985) "Design of Pavements with Interlocking Concrete Blocks” Research Report No. 85-87, Transportation Research Inst., Technion.

Livneh, M. and Ishai, I. (1988)"Development of Pavement Design Methodology for Concrete Block Pavements in Israel. "Proc., 3rd Int. Conf. on Concrete Block Paving, Rome, Italy.

Uzan, J. and Gur, Y. (1989) “Flexible Pavement Design in Urban Street in Israel” Research Report No.89-143, Transportation Research Institute, Technion.

Uzan, J. (1996) “A pavement Design and Rehabilitation System” Transportation Research Record No. 1539, Transportation Research Board.

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