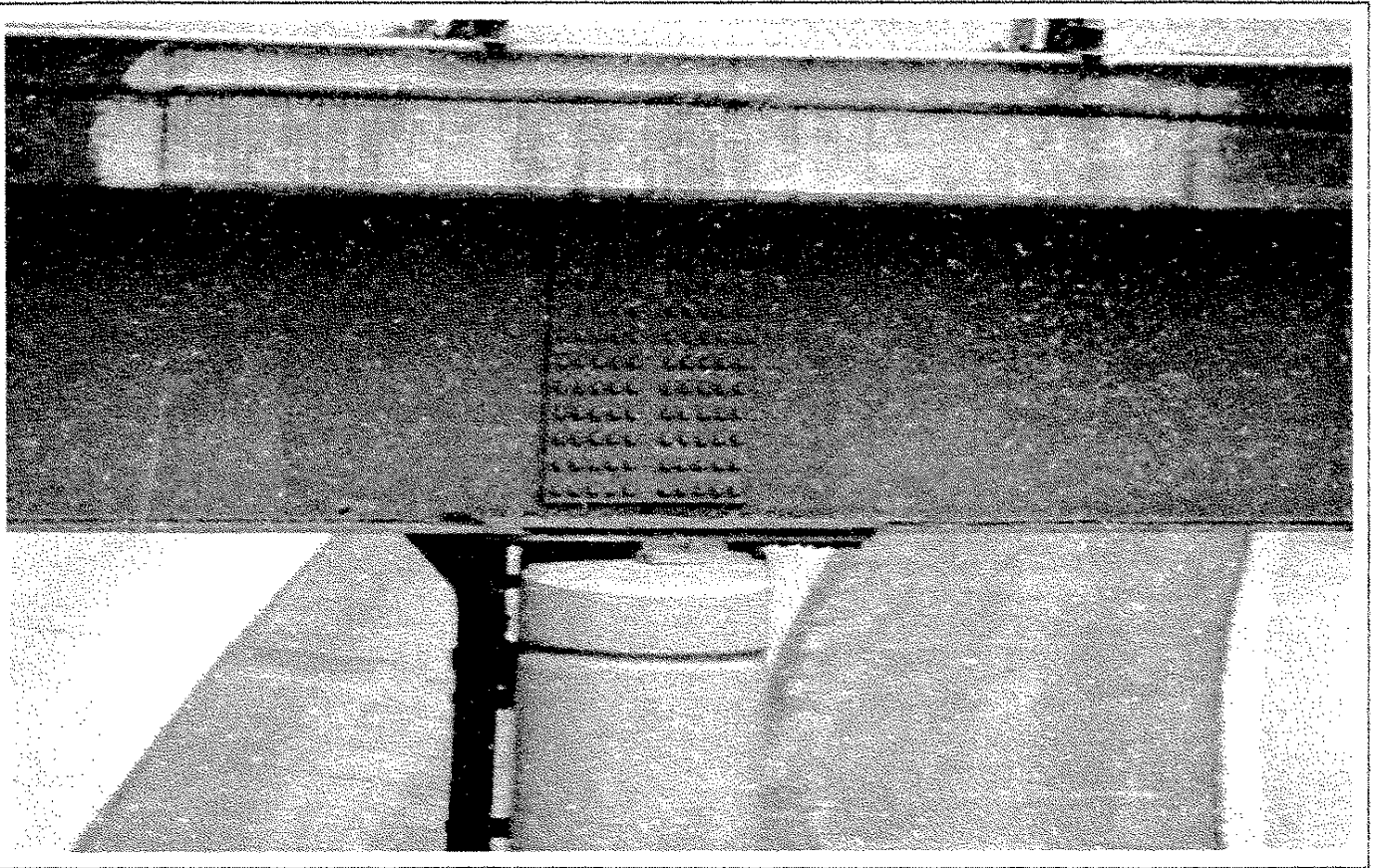


BRIDGE SAFETY ASSURANCE

**SEISMIC
VULNERABILITY
MANUAL**



New York State Department of Transportation

SEISMIC VULNERABILITY MANUAL

NEW YORK STATE
DEPARTMENT OF TRANSPORTATION

STRUCTURES DESIGN AND CONSTRUCTION DIVISION
BRIDGE SAFETY ASSURANCE UNIT

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FOREWORD

The majority of catastrophic bridge failures around the world have occurred for reasons other than those that are primarily condition-based. The collapse of the New York State Thruway Authority's Schoharie Creek Bridge during heavy flooding in April, 1987 is one such example. In order to eliminate or reduce the vulnerability of new and existing bridges to such catastrophic failures, the New York State Department of Transportation (NYSDOT) initiated a comprehensive Bridge Safety Assurance (BSA) Program. This program consists of a multi-step process for identifying potential causes, or modes, of bridge failure and for the subsequent rating of bridges as to the extent of their vulnerability to these failure modes. The procedure that follows clearly outlines the NYSDOT approach to the seismic vulnerability failure mode as it relates to new bridges, existing bridges and bridges programmed for rehabilitation.

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SECTION 1 - INTRODUCTION

- 1.1 Purpose** - The purpose of this document is to describe the NYSDOT procedure for assessing and rating the seismic vulnerability of the bridges in New York State. This procedure is part of the NYSDOT seismic evaluation and retrofit program for highway bridges which is intended to reduce the vulnerability of the state's bridges to failures caused by earthquakes.

The NYSDOT seismic vulnerability assessment is a series of screening and classification steps which result in a vulnerability rating for each bridge. This rating describes the likelihood and the consequence of a failure in terms of the urgency in which corrective actions need to be implemented.

The vulnerability ratings developed under this program are designed to be used in conjunction with similar ratings for other extreme events, such as scour and overload, in order to establish priorities for taking corrective actions on any given bridge.

- 1.2 Seismic Retrofit Process** - The process of seismic retrofitting an inventory of bridges involves the assessment of a number of complex issues and requires considerable professional judgement. An appreciation for the economic, social and technical issues is important to the successful execution of such a program. It is therefore helpful to divide the process into three major stages. These are as follows:

- Vulnerability assessment of the bridge inventory
- Detailed evaluation of deficient bridges
- Implementation of retrofit measures

Figure 1.2 shows these three stages and their interrelation with each other. A brief description of each is given in the following sections.

- 1.2.1 Vulnerability Assessment** - The seismic assessment of a large inventory of bridges is intended to identify those bridges that are seismically deficient and establish an order of priorities for taking corrective actions, i.e. retrofit or replacement. Criteria used for establishing this order are based on degree of vulnerability, and the likelihood and consequences of failure.

The process is comprised of three steps: screening, classifying and rating as illustrated in Figure 1.1. It is intended that these steps be performed sequentially and that once the screening step is complete and a preliminary set of priorities is determined, the remaining two steps are applied in order of these priorities. This will result in a staggered progression of bridges through the assessment process.

Step 1: Screening - The purpose of this step is to develop a preliminary ranking of bridges in the inventory, using information in the data base of the Bridge Inventory and Inspection System (BIIS) [1]. Using such factors as date of construction, seismic acceleration coefficient, importance, span configuration, bearing details, and type of pier and foundation, bridges are assigned to one of four **susceptibility groups**. This grouping is, in effect, a preliminary, 4-level, ranking of the inventory from greatest to least vulnerability. This ranking is later used to determine the order in which bridges are progressed to the classifying step where more detailed assessments are carried out. Details of Step 1: Screening, are given in Section 2 of this Manual.

Step 2: Classifying - The purpose of this step is to evaluate in greater detail the seismic vulnerability of each bridge identified in Step 1 as potentially having inadequate seismic load capacity or details. The order in which this assessment is done is also determined by the results of Step 1. Access to BIN folders, as-built plans and inspection reports will generally be necessary to complete this step, along with one or more site visits to confirm information and obtain additional data which may be missing from the BIN folder. The product of this exercise is a **classification score** which quantifies the potential vulnerability of each bridge relative to other bridges in the inventory. It is also used to assign a **seismic vulnerability class** (high, medium or low) to each bridge which is later used to obtain a vulnerability rating score in the next and final step in this procedure. The methodology used to develop the classification score is largely based on recommendations prepared by the Federal Highway Administration (FHWA) and is published in the Seismic Retrofitting Manual for Highway Bridges [2]. Details of Step 2: Classifying are given in Section 3 of this Manual.

Step 3: Vulnerability Rating - The purpose of this step is to provide a uniform measure of a structure's vulnerability to failure on the basis of its **seismic vulnerability class** and the consequences of failure. The resulting **seismic vulnerability rating** is compatible with similar ratings for other Bridge Safety Assurance (BSA) failure modes and indicates the need for, and the urgency by which, corrective actions should be taken. The rating is calculated by first assigning a **likelihood of failure score** (using the vulnerability class) to the bridge and then adding to it a **consequence of failure score**. This latter score is based on an estimation of the failure type and an exposure score which are calculated in accordance with standard BSA procedures[3]. Details of Step 3: Vulnerability Rating are given in Section 4 of this Manual.

- 1.2.2 Evaluation** - A Structural Integrity Evaluation (SIE) should be carried out before any corrective actions are taken on bridges that have been identified during the Vulnerability Assessment stage (Section 1.2.1) as seismically inadequate. This evaluation, as defined in the NYSDOT Uniform Code of Bridge Inspection [7], includes a detailed analysis of all of a bridge's vulnerability modes, including seismic. The purpose of the SIE is twofold. First, the more detailed seismic analysis will define which component(s) of the structure is seismically vulnerable and quantify its inadequacy. Second, it will be used to design and determine the benefit of any proposed counter measures. An S.I.E. is also required because the vulnerability assessment procedures used in Section 1.2.1 are generally over-conservative in order to assure that, as far as possible, all deficient bridges are identified.

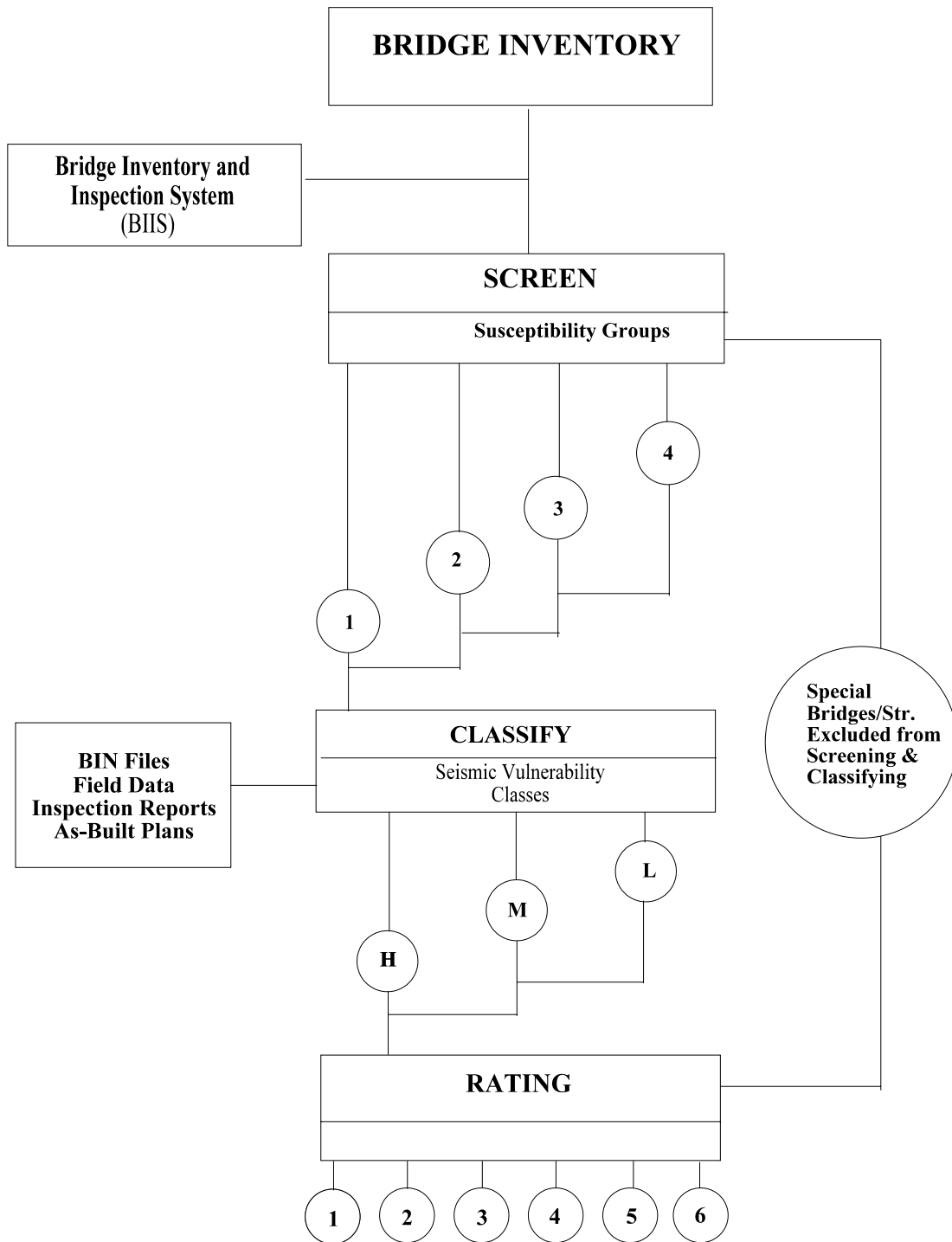


FIGURE 1.1 - Seismic Vulnerability Assessment Procedure

Methods for performing this evaluation generally fall into two categories as follows:

- Capacity/Demand (C/D) ratio methods
- Push-over methods (lateral strength methods of analysis)

C/D methods evaluate each component in a bridge on a member-by-member basis and components with ratios less than unity are identified for corrective action. The method is relatively straightforward to apply and is similar to load rating a bridge for live loads. It is generally conservative and sometimes overly-conservative because it ignores the interaction between the various components of a bridge and the load redistribution that occurs during an extreme event such as an earthquake. Push-over methods address this issue but are more time consuming to apply. Nevertheless this extra effort may be offset by a reduction in the extent and cost of the required corrective actions. Both methods are described in Chapter 3 of the FHWA Retrofitting Manual [2].

1.2.3 Implementation - The design and implementation of appropriate retrofit measures comprise the final stage in the seismic retrofitting process. Corrective measures have been developed for most of the common deficiencies found in highway bridges. These are based on experience with past earthquakes and extensive research and development sponsored by Caltrans and FHWA. They include measures for bearings, seats and expansion joints; columns, cap beams and structural joints; and foundations and sites with poor soil conditions. These options are described in Chapters 4 through 9 of the FHWA Retrofitting Manual [2] as well as other publications such as Caltrans Seismic Design References [4].

1.3 Manual Outline - This manual describes the assessment procedure to be used to determine the seismic vulnerability rating for each bridge in the New York State Bridge Inventory. An outline of this 3-step procedure is given above in Section 1.2.1. where it is shown that this procedure involves screening, classifying and rating processes. Each of these steps is described in detail in manual Sections 2, 3 and 4, respectively. However, this document does not discuss the detailed evaluation of inadequate bridges or the design and implementation of retrofit measures, since both topics are well described in the literature such as the FHWA Seismic Retrofitting Manual for Highway Bridges [2]. Evaluation procedures and retrofit strategies in these publications are generic by design and should be applied to New York State bridges without difficulty. The FHWA Manual may be used as a guide; however, it must be emphasized that the minimum design requirements originally issued under NYSDOT Engineering Instruction 92-46 and incorporated into the New York State Standard Specifications for Highway Bridges [8], shall always be satisfied when retrofitting existing bridges for earthquake forces.

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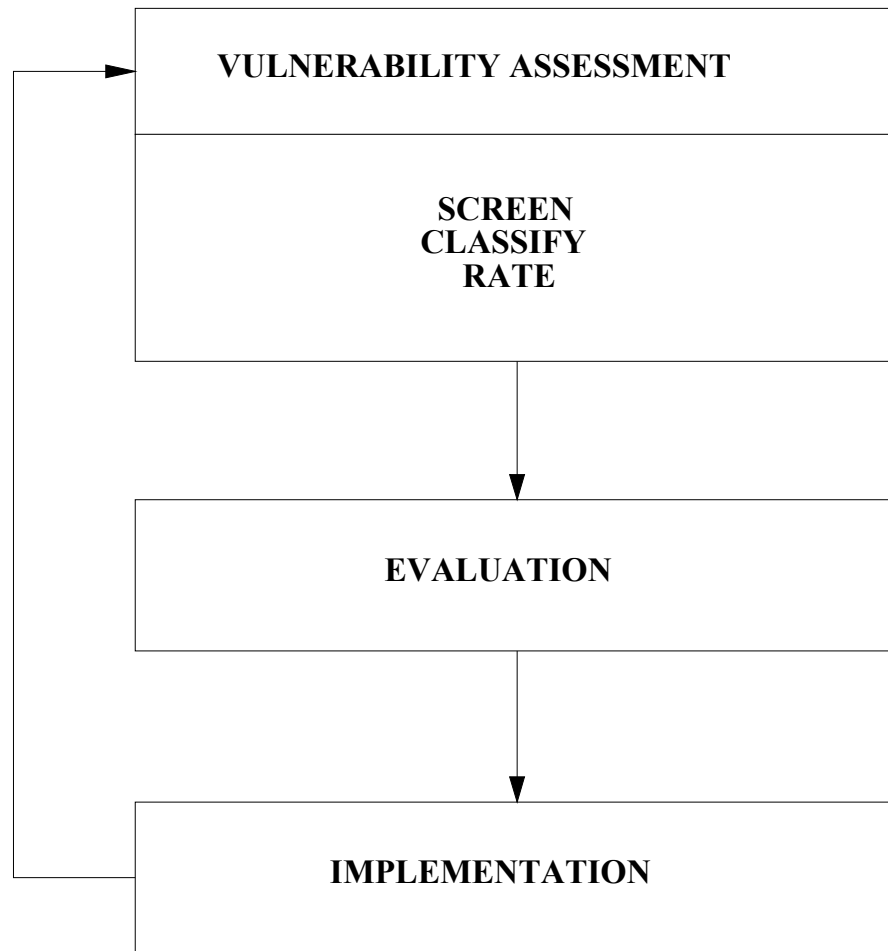


Figure 1.2 - Seismic Vulnerability Assessment and Retrofit Program

SECTION 2 - SCREENING

- 2.1 General** - Screening is the first step in the Vulnerability Assessment program and its purpose is to evaluate a large population of bridges in an efficient manner in order to develop a preliminary ranking of bridge vulnerability. Using only information which is in the data base of the Bridge Inventory and Inspection System (BIIS), bridges are assigned to one of four susceptibility groups according to their assessed vulnerability. No analysis is conducted during this screening. If necessary, refinements to these assessments are made in Section 3: Classifying and again during a Structural Integrity Evaluation (See Section 1.2.2).

Information from BIIS that is used to perform this screening includes:

- Date of construction
- Importance: critical facility, utilities carried, AADT, bypass length, function classification
- Single or multiple spans
- Simple or continuous girders
- Bearing type
- Number of girders per span (girder redundancy)
- Skew
- Pier type
- Footing type

The screening process described below is in two parts: first a preliminary screening to identify those bridges that should be assessed and second the assignment of these bridges to susceptibility groups. These two parts are separately described in the following sections.

- 2.2 Inventory Screening** - The BIIS is a comprehensive data base of highway structures of various types and the first step is to exclude those structures that are either not bridges or bridges deserving special study. The following questions is asked: Is the structure a special type?

- Tunnel or culvert? (Yes: exclude and assign rating of 6). Tunnels and culverts have historically performed very well under seismic loads.
- Arch, suspension or stayed girder? (Yes: perform SIE)
- Moveable bridge? (Yes: perform SIE)
- Railroad or pipeline? (Yes: if over a highway, perform SIE; if not, assign rating of 6)
- Temporary or closed? (Yes: if over a highway, perform SIE; if not, assign rating of 6)
- Long span > 500 feet? (Yes: perform SIE)

The bridge types listed above as needing an SIE should be given an informal classification of high, medium or low, based on engineering judgement and then determine a rating using the rating procedure (See Sections 3 and 4). Using the definitions of vulnerability ratings, (See Appendix C) the Evaluator will have some

guidance on when the Structural Integrity Evaluation should be done. This process is illustrated in Figure 2.1.

2.3 Susceptibility Grouping

2.3.1 General - Once the bridge inventory has been screened as indicated in Section 2.2, the assignment to susceptibility groups can be made. Four groups are defined as follows:

Susceptibility Group 1:	High seismic vulnerability
Susceptibility Group 2:	Moderate-high vulnerability
Susceptibility Group 3:	Moderate-low vulnerability
Susceptibility Group 4:	Low seismic vulnerability

Assignment to one of these four groups is based on the eight structural parameters listed in Section 2.1. This process is shown in Figure 2.2 and described in the next section.

2.3.2 Group Assignments - As shown in Figure 2.2, there are six basic steps to the assignment process and a number of intermediate steps as described below:

Step A: If the bridge is a single span bridge, its vulnerability is limited to bearings and connections at the abutments as described in Steps B and C. If the bridge has multiple spans connectivity, pier and foundation types affect vulnerability, as described in Steps D, E and F below.

Step B: If the bridge has integral abutments it is assigned to Group 4.

Step C1: If the abutment bearings are steel rocker bearings, which have a tendency to overturn during large displacements, the bridge is assigned to Group 2.

C2: If the abutment skew is greater than 30°, the bridge is assigned to Group 2 regardless of bearing type; for smaller skew angles, Group 4 is assigned.

Step D: If the bridge consists of multiple spans, seismic vulnerability is strongly influenced by the connectivity at the piers. This is because continuous girders are inherently more stable than simple spans which are particularly vulnerable to unseating modes of collapse. Continuous girder bridges are examined during Steps E1 through E7 below.

Simply supported spans are considered in Steps F1, F2 and F3 where bearing type, skew and redundancy are checked. Even if all responses are negative, the bridge is assigned to Group 2. There is no need to check pier and footing conditions at this time, since these will be examined when Group 2 bridges are Classified (Section 3).

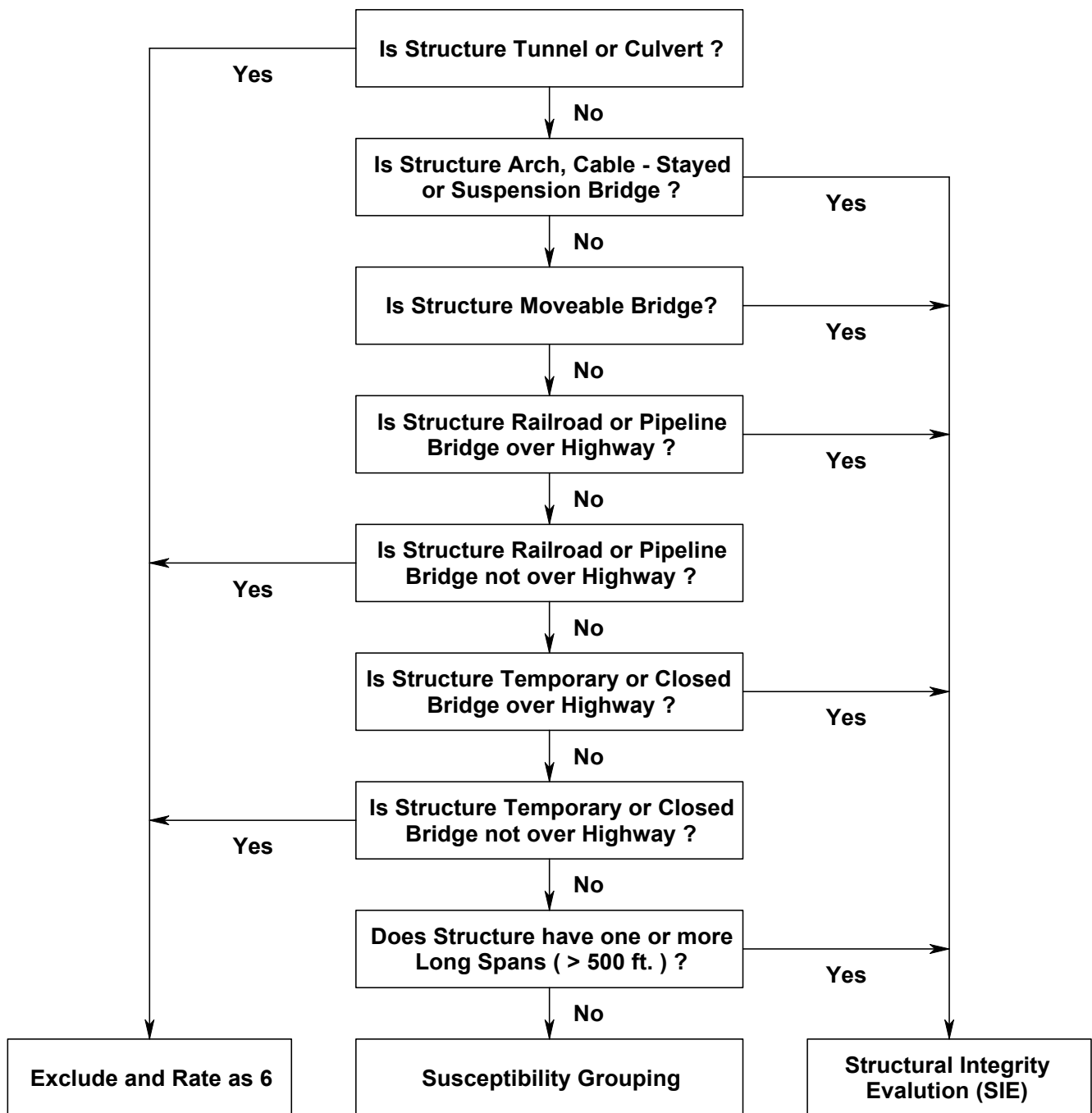


Figure 2.1. Inventory Screening

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- Step E1:** If the continuous girder is supported on steel rocker bearings, the bridge is assigned to Group 2 (see also Steps C1 and F1).
- E2:** If the skew is greater than 30° and/or bridge on curved alignment, the bridge is assigned to Group 2 regardless of bearing type.
- E3:** If the continuous superstructure comprises only 2- or 3-girders or trusses, it has poor redundancy and little resistance to collapse if lateral restraint is lost at an edge girder bearing; the bridge is assigned to Group 2 regardless of bearing type.
- E4:** If the piers are unreinforced (solid concrete or solid stone), the bridge is assigned to Group 2.
- E5:** If each pier is a single column, the bridge is assigned to Group 3.
- E6:** If the piers are timber or steel pile bents, or a timber trestle bent, the bridge is assigned to Group 3.
- E7:** If the footings are concrete and supported on piles or earth, the bridge is assigned to Group 3. Concrete footings on rock are assigned to Group 4. If there are no affirmative response in Steps E1 through E7, Group 4 is assigned.

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- Step F1:** If the simply supported girders are supported on steel rocker bearings, the bridge is assigned to Group 1 (see also Steps C1 and E1).
- F2:** If the skew is greater than 30° and/or bridge on curved alignment, the bridge is assigned to Group 1 regardless of bearing type.
- F3:** If the superstructure comprises only 2- or 3-simple girders or trusses, it has poor redundancy and little resistance to collapse if lateral restraint is lost at an edge girder bearing; the bridge is assigned to Group 1 regardless of bearing type. If there are no affirmative responses in Steps F1 through F3, Group 2 is assigned.

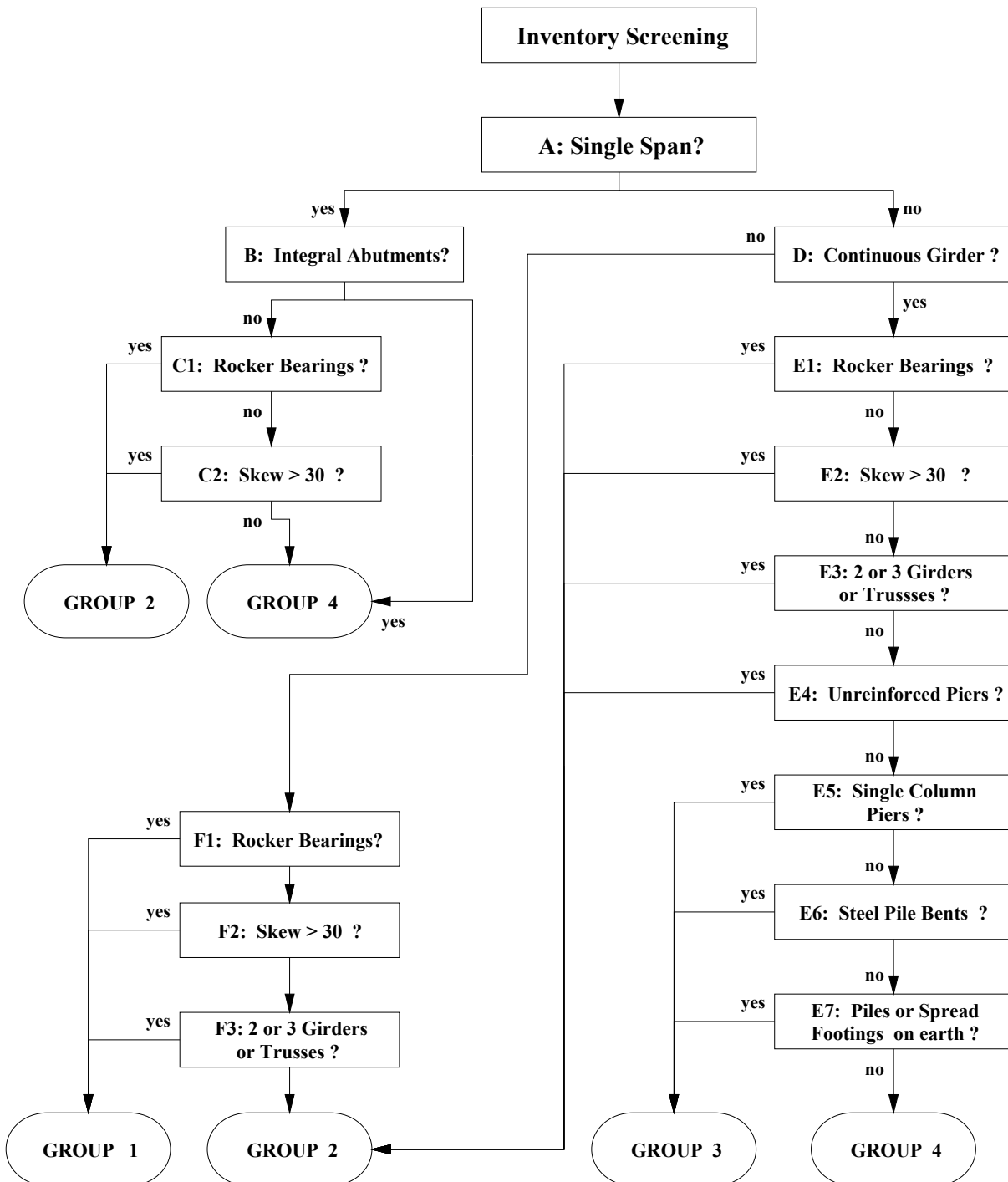


Figure 2.2 - Susceptibility Grouping

SECTION 3 - CLASSIFYING

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- 3.1 General** - The purpose of the classifying step is to assess the vulnerability of a structure to seismic damage. The product of this step is a classification score which serves two purposes: first, it quantifies the potential vulnerability of a bridge to seismic damage relative to other bridges in the classifying process and second, the classification score is used to place a bridge into a high, medium or low **seismic vulnerability class**.

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In addition to the above information, it is also necessary to know the design seismic acceleration coefficient (A) for each bridge site. These coefficients should represent the effective peak acceleration at a site for an earthquake that has a 10% probability of being exceeded in any 50 year period (a return period of approximately 475 years). A map giving such a set of coefficients is contained in Division I-A of the AASHTO Standard Specifications for Highway Bridges [5]. Based upon this map, the NYSDOT Standard Specifications for Highway Bridges [8] divides New York State into three Seismic Performance Categories: Seismic Performance Category 'A', Seismic Performance Category 'B' and the New York City (Downstate) Area. The limits of these Categories are shown in Figure 6A.2-2 of the NYSDOT Standard Specifications for Highway Bridges and reproduced in Appendix 'B' of this manual.

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The classification procedure requires additional information on other parameters which strongly influence seismic performance; including soil type, attached seat widths at expansion joints, and pier reinforcement details. The additional data may be found as a result of a site visit or from information on as-built plans. Where required data is unavailable, some conservative assumptions may be made to complete the classification process.

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The procedures in the classifying process have been adapted from the FHWA Seismic Retrofitting Manual for Highway Bridges [2], and have been designed to provide a degree of uniformity between the results of different evaluating engineers and to ensure that all the factors which affect seismic performance are considered. The procedures are not intended to exclude the judgement of a qualified professional trained in earthquake engineering.

- 3.2 Overview of Classification Process** - Except as noted below, all bridges that have been assigned to susceptibility groups in Section 2.3 are to be classified in accordance with the procedures given in this and subsequent sections. Bridges exempt from this classification process are as follows:

1. If the date of construction is later than 1990, and the bridge, including substructures, has been constructed to NYSDOT Standards as evidenced by contract documents, it can be assumed to have adequate seismic resistance. No remedial actions are required and a rating of 5 is assigned in Section 4 (Table 4.1).
2. If the bridge is located in Seismic Performance Category (SPC) A and it is not a critical facility then seismic assessment is not required and no action is required. A rating of 5 is assigned if the structure is designed to current seismic standards

and the structure is rated a 4 if not designed to current seismic standards, as described in Section 4 (Table 4.1). The reason for excluding these bridges from possible retrofit actions regardless of age or vulnerability, is the very low likelihood of a damaging earthquake occurring during the remaining useful life of the bridge. On the other hand if the bridge is a critical facility, it must be screened for potential vulnerabilities despite the low level of seismic hazard. A procedure for identifying critical bridges is given in Appendix A.

A classification score (CS) is calculated for all non-exempt bridges as:

$$CS = V \cdot E \quad (3.1)$$

where V is a numerical measure of structural vulnerability and E is a seismic hazard rating for the site.

Both V and E are assigned values which can range from 0 to 10 and the value for the classification score (CS) can therefore range from 0 to 100. A low value for CS implies a low seismic risk and a high value for CS implies a high risk. These values for CS (together with engineering judgement) are used to assign **seismic vulnerability classes** as described in Section 3.4.

3.3 Calculation of Classification Scores - As noted above, the classification score is a function of structure vulnerability (V) and seismic hazard (E). Calculation of V and E is described in the following sections. A field evaluation of the bridge will be necessary to complete these calculations. These field visits will be used to confirm inventory data and to obtain additional information used in the assessment procedure.

3.3.1 Vulnerability Score (V) - Although the performance of a bridge is based on the interaction of all its components, it has been observed in past earthquakes that certain bridge components are more vulnerable to damage than others. These are: (a) connection bearings and seats, (b) piers, (c) abutments, and (d) soils. Of these, bridge bearings seem to be the most economical to retrofit. For this reason, the vulnerability score to be used in the classification process is determined by examining the connections, bearings and seat details separately from the remainder of the structure. Connections refer to whether the superstructure is continuous or interrupted by joints. A separate vulnerability score V_1 , is calculated for these components. The vulnerability score for the remainder of the structure, V_2 , is determined from the sum of the vulnerability scores for each of the other components (piers, abutments and soils) which are susceptible to failure. The overall score for the bridge is then selected from V_1 and V_2 according to severity of the seismic hazard (Seismic Performance Category, SPC)* and the importance (criticality)** of the bridge as follows:

*Seismic Performance Categories (SPC) are defined for each New York State County in Appendix 'B'.

**Note: A critical bridge is defined in Appendix A (see also Step 2 of the screening procedure (Section 2.2)).

For bridges in SPC A:

$$V = 0 \quad \text{for a non-critical bridge}$$

(Screened out and rated as 5 or 4, Sec. 3.2)

$$V = V_1 \quad \text{for a critical bridge}$$

For bridges in SPC B:

$$V = V_1 \quad \text{for a non-critical bridge}$$

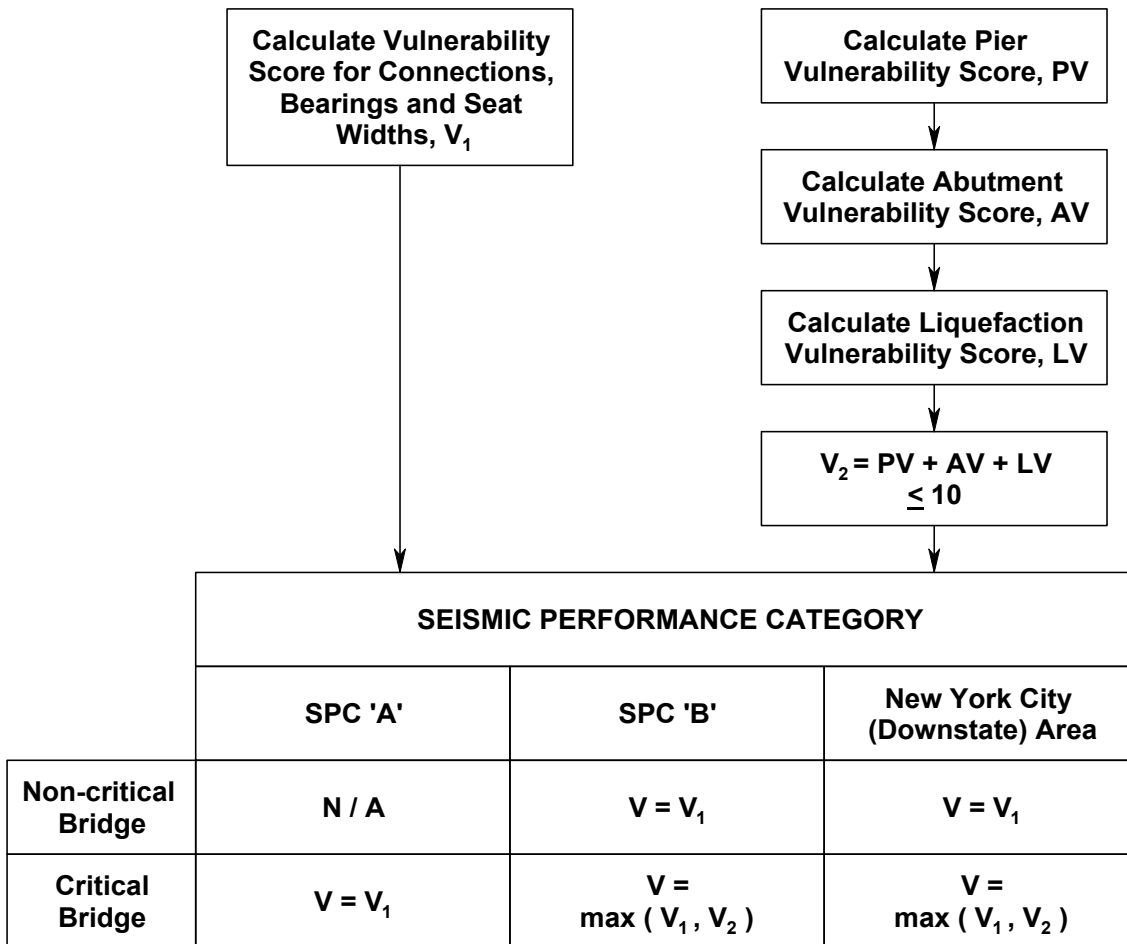
$$V = \text{maximum of } V_1 \text{ or } V_2 \quad \text{for a critical bridge}$$

For bridges in NYC
(Downstate) Area :

$$V = V_1 \quad \text{for a non-critical bridge}$$

$$V = \text{maximum of } V_1 \text{ or } V_2 \quad \text{for a critical bridge}$$

This process is summarized below.



Fi

Figure 3.1 - Assignment of Bridge Vulnerability Score (V)

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The determination of these vulnerability scores requires considerable engineering judgment. In order to assist in this process, a methodology is given in Sections 3.3.1.1 and 3.3.1.2.

Vulnerability scores (V) may assume any value between 0 and 10. A rating of 0 means a very low likelihood of unacceptable seismic damage, a 5 indicates a moderate vulnerability to collapse or a high vulnerability to loss of access, and a 10 means a high vulnerability to collapse. This should not be interpreted to mean that the vulnerability score must assume one of these three values; intermediate values may be assigned.

A comparison of the above two vulnerability scores, V_1 and V_2 , can be used to obtain an indication of the type of retrofitting needed, especially for critical bridges in SPC B or the NYC (Downstate) Area. If the vulnerability score for the bearings V_1 is equal to or less than the vulnerability score of other components V_2 , simple retrofitting of only the bearings may be of little value. Conversely, if the bearing score is greater, then benefits may be obtained by retrofitting only the bearings.

3.3.1.1 Vulnerability Score for Connections, Bearings and Seatwidths, V_1 - Bearings are used to transfer loads from the superstructure to the substructure and between superstructure segments at in-span hinge seats. For the purpose of this discussion, bearings are considered to include restraints provided at these locations, including shear keys, restrainer bars, and the like. Bearings may be "fixed" bearings, which do not provide for translational movement, or expansion bearings, which do permit such movements, as shown in Figure 3.2. A bearing may provide for translation in one orthogonal direction but not in the other.

Five basic types of bearings are used in bridge construction. These are:

- (1) The rocker bearing, which is generally constructed of steel and permits translation and rotational movement. It is considered to be the most seismically vulnerable of all bridge bearings because it usually has a large vertical dimension, is difficult to restrain, and can become unstable after a limited movement and overturn. It also fails under transverse loading.
- (2) The roller bearing, which is also usually constructed of steel. It is stable during an earthquake, except that it can become misaligned and horizontally displaced. It has minimal transverse load resistance.

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FIXED BEARINGS



EXPANSION ROCKER BEARINGS

Figure 3.2 - Typical Seismically Vulnerable Bearings.

- (3) The elastomeric bearing pad, which has become popular in recent years. It is constructed of a natural or synthetic elastomer and may be internally reinforced with steel shims. It relies on the distortion of the elastomer to provide for movement. This bearing is generally stable during an earthquake, although it has been known to "walk out" under severe shaking due to inadequate fastening.

"Walking out" is mitigated through the use of an internal shear pin or bearing plates with anchor bolts.

- (4) The sliding bearing, in which one surface slides over another and which may consist of almost any material from an asbestos sheet between two concrete surfaces to PTFE (teflon and similar materials) and stainless-steel plates. Keeper bars can resist transverse loads when multiple bearings are used.
- (5) High-load, multi-rotational bearings such as pot, disc, and spherical bearings. These engineered bearings usually have adequate strength for earthquake loads, but have failed in their connections (i.e. keeper bars and anchor bolts) in past earthquakes.

Transverse restraint of the superstructure is almost always provided at the bearings. Common types of restraint are shear keys, keeper bars, or anchor bolts. Restraints are usually not ductile, and are subjected to large seismically induced forces resulting from a redistribution of force from ductile components such as columns. In addition, when several individual bearings with keeper bars are present at a support, the keeper bars may not resist load equally because of slight variations in clearances. Therefore, individual keeper bars may be subjected to very high forces. In vulnerable structures, collapse may occur due to loss of support resulting from large relative transverse or longitudinal movement at the bearings. Table 3.1 describes the types of bearings that can or can not be expected to provide adequate transverse resistance. The expected movement at a bearing is dependent on many factors and cannot be easily calculated. The NYSDOT Specifications require a minimum support length at all bearings in newly constructed bridges [8]. Because it is very difficult to predict relative movement, the minimum support lengths, N , as required by the NYSDOT Specifications, may be used here as the basis for checking the adequacy of longitudinal support lengths. The definition and equation for determining N is shown in Appendix "D".

TABLE 3.1 (Revised 11/2004)	
Column A Transverse Restraint Expected	Column B Transverse Restraint Not Expected
1. Substructure with concrete shear keys.	1. Rocker bearings.
2. Elastomeric pad with center pin.	2. Roller bearings.
3. Elastomeric pad with center pin and anchor bolts.	3. Elastomeric bearings with bearing plates and anchor bolts.
4. Sliding bearings, or multi-rotational bearings, with guide bars and 4 or more girders in section.	4. Sliding bearings, or multi-rotational bearings, without guide bars or with 3 or fewer girders in the section.

Support skew has a major effect on the performance of bridge bearings. In this manual, skew is defined as the angle between the support centerline and a line normal to the bridge centerline. Rocker bearings have been the most vulnerable in past earthquakes. At highly skewed supports, these bearings may overturn during even moderate seismic shaking. In such cases, it is necessary to consider the potential for collapse of the span, which will depend to a large extent on the geometry of the bearing seat. Settlement and vertical misalignment of a span due to an overturned bearing may be a minor problem, resulting in only a temporary loss of access which can be restored, in many cases, by backfilling with asphalt or other similar material. **(The potential for total loss of support should be the primary criteria when assessing the vulnerability of the bearings.)**

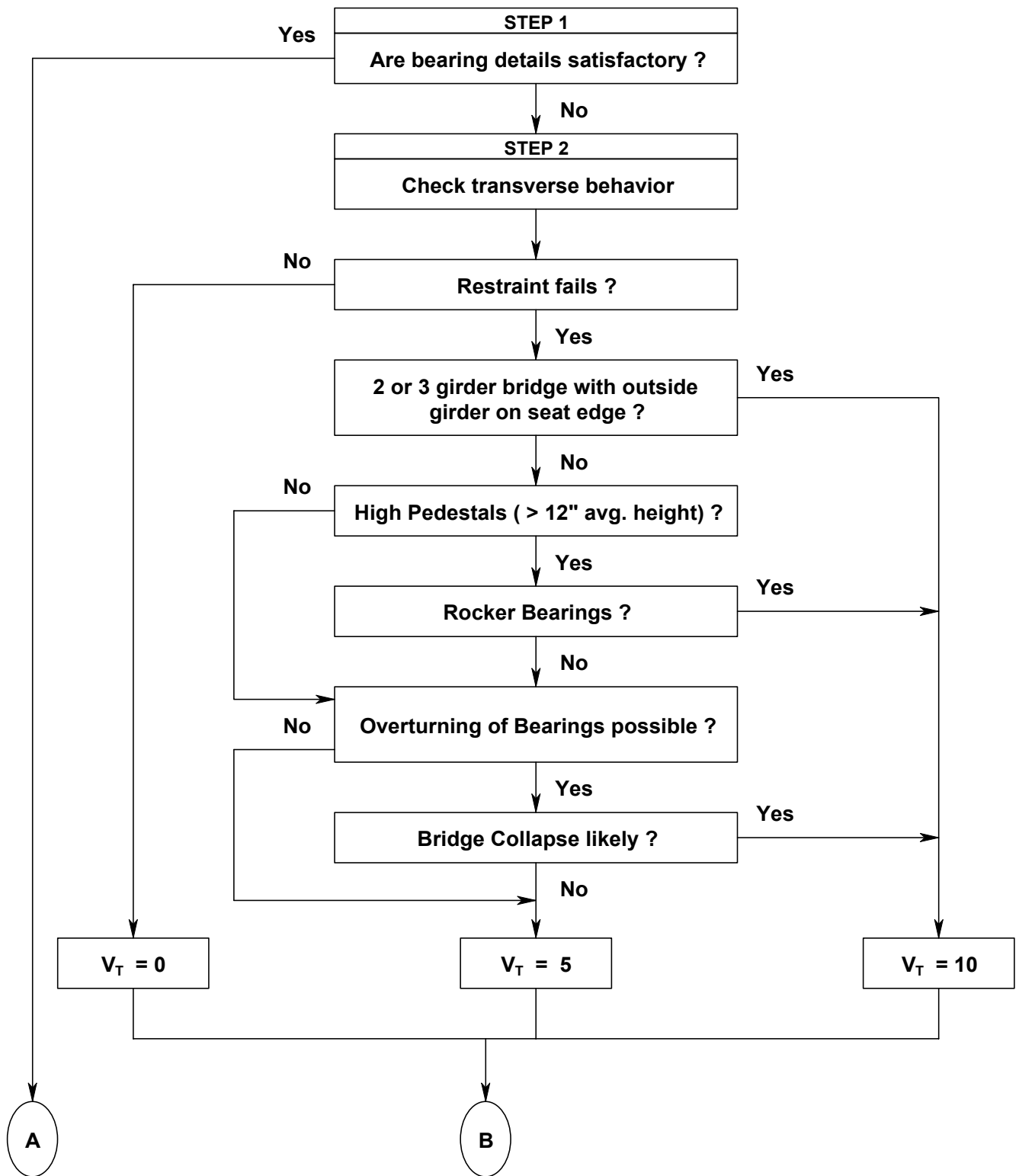


Figure 3.4a - Calculation of Bearing Vulnerability

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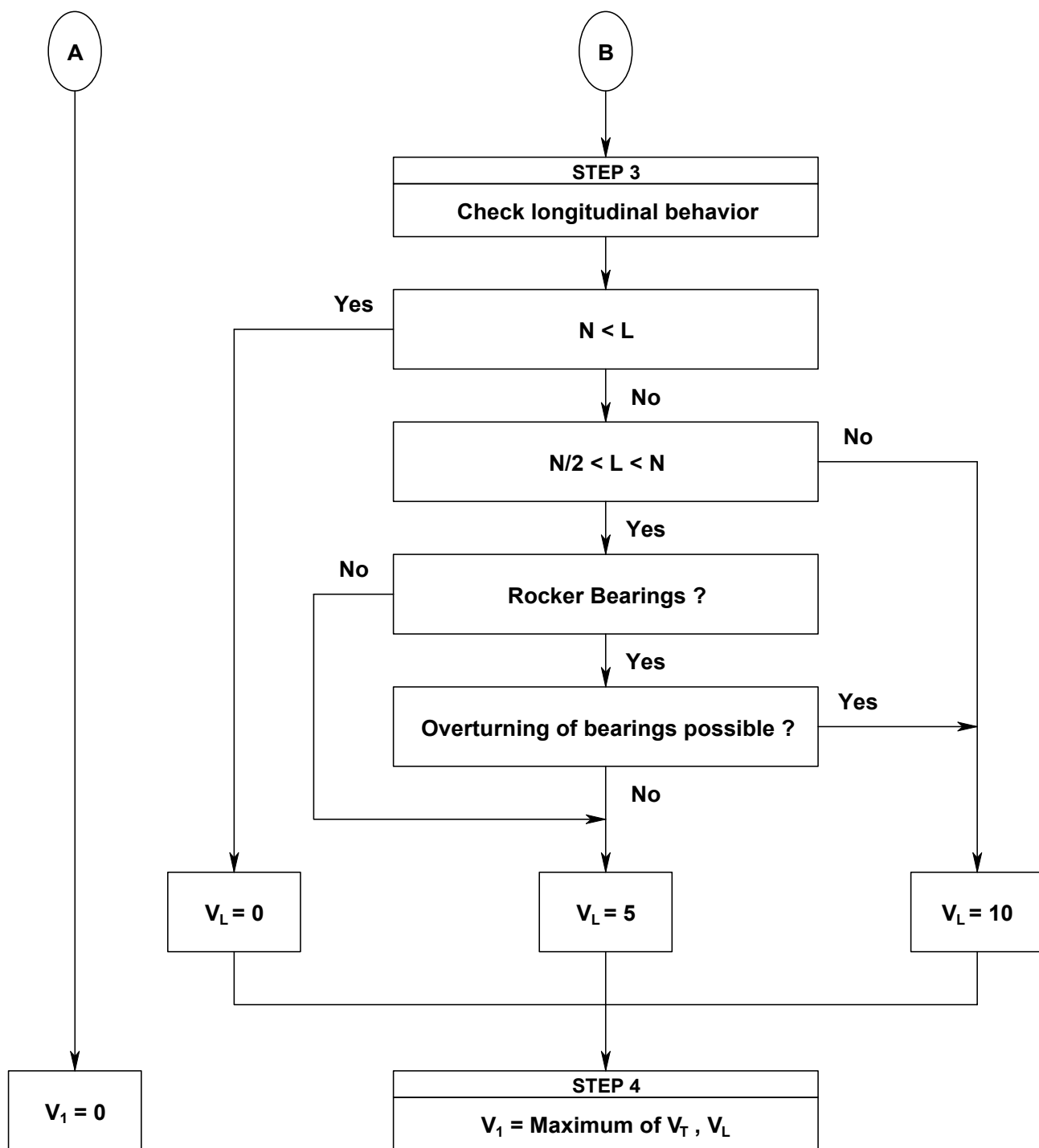


Figure 3.4b - Calculation of Bearing Vulnerability (Cont'd)

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A suggested step-by-step method for determining the vulnerability score for connections, bearings, and seats (V_1) is detailed in the flow chart of Figure 3.4 and is described below. Note that V_1 need not be calculated for non-critical bridges in SPC A. See Section 3.1.1 and Figure 3.1.

Step 1: Determine if the bridge has satisfactory bearing details. These bridges include:

- a. Continuous superstructures with integral abutments.
- b. Continuous superstructures with seat-type abutments where all of the following conditions are met:
 - (1) Either (a) the skew is less than 20° , or
(b) the skew is greater than 20° but less than 30° and the length-to-width ratio of the bridge deck is greater than 1.5.
 - (2) Rocker bearings are not used.
 - (3) The bearing seat under the abutment end-diaphragm is continuous in the transverse direction and the bridge has more than three girders.
 - (4) The support length is equal to, or greater than, the minimum required support length (N) as defined by the NYSDOT Standard Specifications for Highway Bridges [8].

If the bearing details are determined to be satisfactory, a vulnerability score V_1 , of 0 may be assigned and the remaining steps for bearings omitted. Bridges with unsatisfactory bearing details are addressed in Steps 2 through 4.

Step 2: Determine the vulnerability to structure collapse or loss of bridge access due to transverse movement, V_T .

Before significant transverse movement can occur, the transverse restraint must fail. If this occurs, superstructure girders are vulnerable to loss of support if either of the following conditions exist:

- a. Individual girders are supported on rocker bearings and individual pedestals or columns. The pedestals/columns have an average height greater than 300 mm (12 inches).
- b. The exterior girder in a 2- or 3-girder bridge is supported near the edge of a bearing seat (less than 200 mm (8 inches)) regardless of whether the bearings are on individual pedestals or not.

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In either of these cases, the vulnerability score, V_T , should be 10.

Steel rocker bearings have been known to overturn transversely, resulting in a permanent superstructure displacement. These bearings are particularly vulnerable when the support skew is greater than 30° . When bearings are vulnerable to a toppling failure but structure collapse is unlikely as determined by a. and b. above, the vulnerability score, V_T , should be 5. If collapse is likely, V_T should be 10.

Step 3: Determine the vulnerability of the structure to collapse or loss of access due to excessive longitudinal movement, V_L .

If the longitudinal support length measured in a direction perpendicular to the support is less than one times, but greater than one-half times, the required longitudinal support length (N), the vulnerability score, V_L , shall be assigned a value of 5. If, in addition, rocker bearings are present and are vulnerable to overturning, a value of 10 for V_L should be used. If the longitudinal support length is less than one-half of the required longitudinal support length, then a vulnerability score, V_L , of 10 should be assigned regardless of bearing type.

Step 4: Calculate vulnerability score for connections, V_1 , from values V_T and V_L ; i.e., $V_1 = \text{maximum value of } V_T \text{ or } V_L$.

3.3.1.2 Vulnerability Score for Piers, Abutments, and Liquefaction Potential, V_2 - The vulnerability rating for the other components in the bridge that are susceptible to failure, V_2 , is calculated from the individual component ratings as follows:

$$V_2 = PV + AV + LV \leq 10 \quad (3.2)$$

where PV = Pier vulnerability score
 AV = Abutment vulnerability score
 LV = Liquefaction vulnerability score

Note that V_2 need only be calculated for critical bridges in SPC B or the NYC (Downstate) Area. See Section 3.3.1 and Figure 3.1.

Methods for calculating each of these component scores are given in the following sections.

A. Pier Vulnerability Score, PV - Piers generally add to the seismic vulnerability of bridges. Each type of pier design behaves uniquely when subjected to seismic loading.

Step 1: Assign a pier vulnerability score, PV , of 0 if bearing keeper bars or anchor bolts can be relied upon to fail (Section 3.3.1.1 and Table 3.1), eliminating the transfer of load to the piers.

Step 2: Masonry or stone piers receive a vulnerability score, PV, of 10.

Step 3: If piers and footings have adequate transverse steel, detailed in as-built plans, as required by the NYSDOT Specifications, assign a pier vulnerability score, PV, of 0.

Step 4: If none of the above apply, use one of the following assessment procedures for the type of pier in question.

- 1. Solid Piers - Gravity Type** - Generally gravity type piers are of old construction and are either unreinforced or very lightly reinforced. They may experience severe cracking when subjected to seismic loads. Assign a pier vulnerability score, PV, equal to 10.
- 2. Solid Piers - Cantilever Type** - Generally solid cantilever piers have more reinforcement than gravity type piers. They are also influenced by the effects of skew, superstructure continuity and strength of reinforcement. Scores for these factors, R, are shown in Table 3.2. Therefore these types of piers receive a base vulnerability score, BV, equal to 6 and are modified by R as shown below:

$$PV = BV - R \quad (3.3)$$

- 3. Multi-column Piers** - Piers with multiple columns act differently than do solid piers*. Pier columns have failed in past earthquakes due to lack of adequate transverse reinforcement and/or poor structural details. Excessive ductility demands from seismic loading have resulted in column failure in shear or flexure. In past earthquakes some columns have failed in shear, resulting in column disintegration and vertical displacements. Column failure may also occur due to pullout of the longitudinal reinforcing steel, mainly at the footings. Piers with columns on top of a solid plinth are generally controlled by the column behavior with the effective height of the column being measured from the top of the plinth to the bottom of the cap beam.

Multi column piers with known reinforcement details are assessed using the procedures in Parts A and B. Piers with unknown reinforcement details are assessed in Part C.

Part A: Column vulnerability due to shear failure.

$$CV = Q - R \quad (3.4)$$

where

$$Q = 13 - 6 \left[\frac{L_c}{P_s F_b \max} \right] \quad (3.5)$$

L_c = effective column length.

P_s = amount of main reinforcing steel expressed as a percent of the column cross-sectional area.

- F = framing factor:
 2 for multi-column bents fixed top and bottom.
 1 for multi-column bents fixed at one end.
 1.5 for box girder superstructure with a single-column bent fixed at top and bottom.
 1.25 for superstructures other than box girders with a single-column bent fixed at top and bottom.
- b_{max} = maximum transverse column dimension.
- R = the number of points to be deducted from Q for factors known to reduce susceptibility to shear failure, as shown in Table 3.2.

Table 3.2. Values for R. (Revised 11/2004)	
Factor	R
Acceleration coefficient, $A < 0.4$	3
Skew $\leq 20^\circ$	2
Continuous superstructure, integral abutments of equal stiffness and length-to-width ratio < 4	1
Grade 40 (or below) reinforcement	1

Values of CV less than zero or greater than 10 should be assigned values of 0 and 10, respectively.

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Note that Equation 3.5 was empirically derived based on observations of column shear failure in bridges during the San Fernando earthquake in 1971. The derivation is given in Appendix B of the 1983 Retrofit Guidelines [6]. This expression has since been checked against column failures in the Northridge earthquake (1994) and was found to be a reliable indicator of column damage. However, the columns in this empirical data set are short-medium height and Equation 3.5 may not apply to tall and/or slender columns. In these cases, special studies may be undertaken to estimate Q, R, and CV.

Part B: Pier vulnerability due to flexural failure at column reinforcement splices.

To account for flexural failure at column splices, CV should be set equal to 7 for single-column bents supporting super-structures longer than 90 m (300 ft), or for superstructures with expansion joints where the column longitudinal reinforcement is spliced at a potential plastic hinge location.

Part C: Where reinforcement details are unknown, assign a Q value equal to 10 for piers greater than 7m (23 ft.) high, measured from bottom of footing to top of cap beam. Shorter piers, 7m (23ft.) in height and shorter, receive a Q value of 7. Calculate CV using equation 3.4.

4. Assign overall pier vulnerability score, PV to the highest value calculated for CV in Parts A, B or C.

B. Abutment Vulnerability Score, AV - Abutment failures during earthquakes do not usually result in total collapse of the bridge. This is especially true for earthquakes of low-to-moderate intensity. Therefore, the abutment vulnerability rating should be based on damage that would temporarily prevent access to the bridge.

One of the major problems observed in past earthquakes has been the settlement of approach fill at the abutment. Large fill settlements are possible in the event of structural failures at the abutments due to excessive seismic earth pressures or seismic forces transferred from the superstructure. Certain abutment types, such as spill-through abutments and those without wing walls, may be more vulnerable to this type of damage than others. Except in unusual cases, the maximum abutment vulnerability score, AV, will be 5. High unreinforced masonry or laid-up stone abutments receive an abutment vulnerability score, AV = 7.

For bridges in New York State, AV = 0 unless both of the following conditions are satisfied, in which case AV = 5. These conditions are:

- a. The bridge crosses water, and
- b. The expected fill settlement is greater than 150 mm (6 inches).

Expected fill settlements for bridges over water in New York State may be estimated at one percent of the fill height measured from the roadway pavement to the base of the embankment. Intermediate values for AV (i.e., between 0 and 5) may be assigned based on the presence of wing walls and the type of abutment.

C. Liquefaction Vulnerability Score, LV - Although there are several possible types of ground failure that can result in bridge damage during an earthquake, instability resulting from liquefaction is the most significant. The vulnerability rating for foundation soil is therefore based on:

- a. A quantitative assessment of liquefaction susceptibility.
- b. The magnitude of the acceleration coefficient.
- c. An assessment of the susceptibility of the bridge structure itself to damage resulting from liquefaction-induced ground movement.

The vulnerability of different types of bridge structures to liquefaction has been illustrated by failures during past earthquakes. Observed damage has confirmed that bridges with continuous superstructures and supports can withstand large translational displacements and usually remain serviceable with minor repairs. However, bridges with discontinuous super-structures and/or non-ductile supporting members are usually severely damaged as a result of liquefaction. These observations have been taken into account in developing the vulnerability scoring procedure described below. The procedure is based on the following steps:

Step 1: Determine the susceptibility of foundation soils to liquefaction.

High susceptibility is associated with the following conditions:

- a. Where the foundation soil providing lateral support to piles or vertical support to footings comprise, on average, saturated loose sands, saturated silty sands, or non-plastic silts.
- b. Where similar soils underlie abutment fills or are present as continuous seams, which could lead to abutment slope failures.

Moderate susceptibility is associated with saturated foundation soils that are, on average, saturated medium dense soils; e.g., compact sands.

Low susceptibility is associated with foundation soils that are, on average, dense soils.

Step 2: Use Table 3.3 to determine the potential for liquefaction-related damage where susceptible soil conditions exist.

Table 3.3. Potential for Liquefaction-Related Damage.

Soil Susceptibility to Liquefaction	Potential for liquefaction-related damage.
low	low
moderate	low
high	moderate

Step 3: Bridges subjected to moderate liquefaction-related damage shall be assigned a vulnerability rating, LV, of 5. This rating should be increased to between 6 and 10 if the vulnerability rating for the bearings, V_b , is greater than or equal to 5.

Step 4: Bridges subjected to low liquefaction-related damage shall be assigned a vulnerability rating, LV, of 0.

3.3.2 Seismic Hazard Score (E) - In this procedure, seismic hazard is a function of the seismic performance category (SPC) and the site coefficient which allows for soil amplification effects. The seismic hazard score is therefore defined as follows:

$$\text{For bridges in SPC A: } E = 1.1 S \quad (3.5 \text{ a})$$

$$\text{For bridges in SPC B: } E = 2.4 S \quad (3.5 \text{ b})$$

$$\begin{array}{l} \text{For bridges in NYC} \\ \text{(Downstate) Area: } E = 2.4 S \end{array} \quad (3.5 \text{ c})$$

where S = site coefficient^{*}.

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It will be seen that E ranges from 1.1 (SPC 'A', $S = 1$) to 8.4 (NYC Area, $S = F_v = 3.5$) in New York State.

For SPC 'A' and SPC 'B' bridges:

When the soil profile can be determined with confidence, Table 3.4 should be used to obtain the site coefficients. If there is insufficient data for this purpose, Table 3.5 may be used to obtain the site coefficients.

Table 3.4. Site Coefficient, S.

Soil Profile Type	Site Coefficient
I	1.0
II	1.2
III	1.5
IV	2.0

Soil Profiles are defined as follows:

Soil Profile Type I

A soil profile composed of rock of any description, either shale-like or crystalline in nature, or of stiff soils where the soil depth is less than 60 m (200 ft) and the soils overlying rock are stable deposits of sands, gravels, or stiff clays, shall be taken as Type I.

Soil Profile Type II

A soil profile with stiff cohesive or deep cohesionless soil where the soil depth exceeds 60 m (200 ft) and the soil overlying the rock are stable deposits of sands, gravels, or stiff clays, shall be taken as Type II.

Soil Profile Type III

A soil profile with soft to medium-stiff clays and sands, characterized by 9 m (30 ft) or more of soft to medium-stiff clays with or without intervening layers of sand or other cohesionless soils, shall be taken as Type III.

Soil Profile Type IV

A soil profile with soft clays or silts greater than 12 m (40 ft) in depth shall be taken as Type IV.

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*Site Coefficient, S, and Soil Profile Types from Table 3.4 or Table 3.5 may be used for SPC 'A' and SPC 'B' bridges only. For NYC (Downstate) Area bridges, see Section 6B and Appendix to Section 6B-2 in Division I-A of the NYSDOT Standard Specifications for Highway Bridges [8].

Site Coefficients F_a (Table 1.4.2.3a) or F_v (Table 1.4.2.3b), for Soil Profile Types A - E, may be substituted for Site Coefficient, S, in Equation 3.5c.

Table 3.5. Alternative Site Coefficients, S^1

Site ²	Soil Profile	Site Coefficient
land or water crossing	rock	1.0
land crossing	all soils	1.2
water crossing ³	all soils except deep deposits of soft clay or silt ⁴	1.5
water crossing ³	deep deposits of soft clay or silt ⁴	2.0

- Notes:
1. This table of site coefficients may be used when soil properties are not known in sufficient detail to determine the soil profile types used in Table 3.4.
 2. If a bridge crosses both water and land, the requirements for water crossings shall govern.
 3. Water crossings include marshes and wetlands.
 4. "Deep" deposits are those that exceed 12m (40 ft) in thickness.

For NYC (Downstate) Bridges:

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See Section 6B and Appendix to Section 6B-2 in Division I-A of the NYSDOT Standard Specifications for Highway Bridges [8]. Site Coefficients F_a (Table 1.4.2.3a) or F_v (Table 1.4.2.3b), for Soil Profile Types A - E, may be substituted for Site Coefficient, S , in Equation 3.5c.

- 3.4 Assignment of Seismic Vulnerability Class** - A seismic vulnerability class is assigned to each bridge based on the classification score calculated in Section 3.3, and in accordance with ranges defined in Table 3.6.

Table 3.6. Seismic Vulnerability Classes

Classification Score, CS	Vulnerability Class
> 70	High
25 - 75	Medium
< 30	Low

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Overlapping ranges are used to provide the evaluator with some discretion in assigning a vulnerability class. For bridges in New York State, the maximum value for the Classification Score is 84 ($V = 10$, $E = 8.4$). Bridges that are determined to have High or Medium Seismic Vulnerability are progressed to the Rating Step (Section 4) ahead of those with Low Vulnerability. These bridges might also be recommended for interim seismic retrofitting, should they be judged to be particularly vulnerable, and the consequences of failure are clearly unacceptable.

SECTION 4 - RATING

4.1 General - The Vulnerability Rating process is common to all six identified BSA failure modes and it is intended to provide a uniform measure of a structure's vulnerability to failure on the basis of the likelihood of a failure occurring and the consequences of a failure.

There are six possible vulnerability ratings as shown in Table 4.1. The six ratings indicate the type of corrective actions needed to reduce the failure vulnerability of a bridge and the urgency in which these actions should be implemented. Definitions are found in Appendix C.

Figure 4.1 shows an overview of the rating process and a detailed description is found in Section 4.2. Bridges may be rated without the use of this manual, however complete documentation justifying the rating must be submitted to the Structures Division.

Table 4.1 Vulnerability Rating Descriptions

RATING	DESCRIPTION
1	Safety Program Watch
2	Safety Program Alert
3	Capital Program
4	Inspection Program
5	No Action
6	Not Applicable

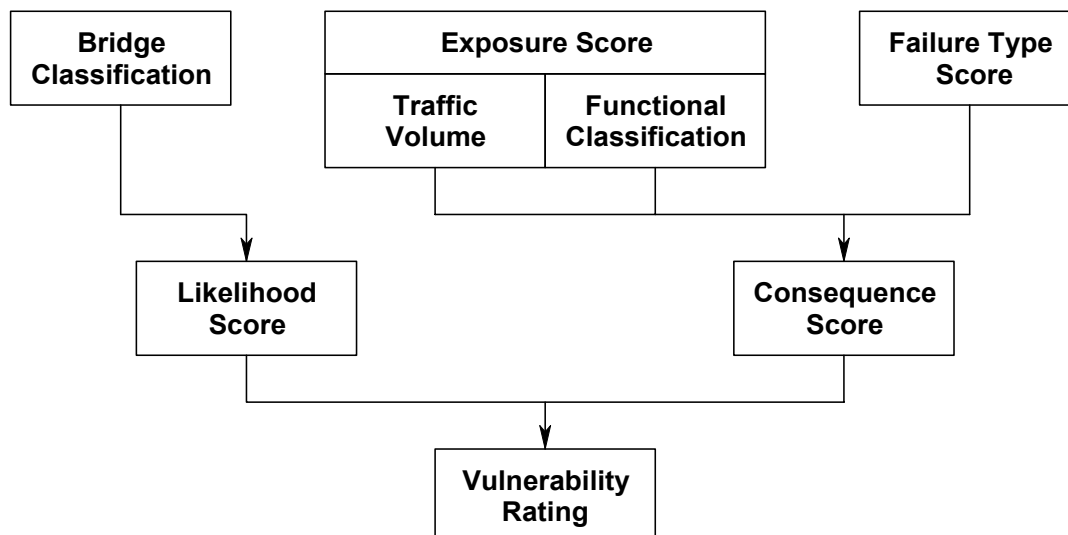


Figure 4.1 - Vulnerability Rating Procedure

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4.2 Rating Procedures - The vulnerability rating process is similar to the classifying process, in that scores are assigned to evaluate the likelihood and consequence of a failure and then these rating scores are combined, as shown in Equation (4.1), to determine the vulnerability rating score.

$$\text{Vulnerability Rating Score} = \text{Likelihood Score} + \text{Consequence Score} \quad (4.1)$$

The vulnerability rating (1 through 6) is determined using the rating score ranges shown in Table 4.2. Overlapping ranges are provided to allow the evaluator some discretion in choosing the appropriate rating. A rating outside the recommended ranges may be used, however complete documentation must be submitted to the Structures Division.

Table 4.2 Vulnerability rating score ranges

Rating	Scoring Range
1	> 15
2	13 - 16
3	9 - 14
4	< 15
5	< 9
6	---

The likelihood and consequence scores are weighted equally in the rating equation. The likelihood score is determined using the results of the classifying process and the consequence score is determined on the basis of the type of failure which is anticipated and the public exposure to that failure.

Figure 4.2 can be used as a worksheet for completing the ratings and as a summary sheet for the results. Detailed descriptions of the criteria for evaluating the likelihood and consequence of a failure are found in Sections 4.2.1 and 4.2.2 respectively.

Bridges which are not vulnerable to a particular failure mode should be rated 6, for that mode. For instance, bridges not over water are not vulnerable to hydraulic failures, and similarly, concrete bridges are not vulnerable to the steel detail failures. In these instances the vulnerability rating score can be disregarded and a rating of 6 assigned to the structure.

4.2.1 Likelihood of a Failure - The likelihood of failure score is determined using the results

of the classifying process. If available, the results of a detailed engineering analysis may also be used to supplement the results of the classifying process. Table 4.3 provides scores which should be assigned to the different vulnerability categories.

The vulnerability classes (High, Medium and Low) are the same as previously defined in Sections 3.1 and 3.4 of the classifying step. If there is no vulnerability to a particular failure mode the Vulnerability Rating Score shall be zero. The likelihood score determined from Table 4.3 should be used in Equation (4.1) to determine the vulnerability rating score.

Table 4.3 Likelihood of failure scores

Vulnerability Class	Likelihood Score
High	10
Medium	6
Low	2
Not Vulnerable	0

4.2.2 Consequence of Failure - The consequence of failure is evaluated on the basis of the type of failure the bridge is prone to and the exposure to the public that a failure would cause. The result of this evaluation will be a consequence score determined as shown in Equation (4.2). This score is used in Equation (4.1) to determine the vulnerability rating score.

$$\text{Consequence Score} = \text{Failure Type Score} + \text{Exposure Score} \quad (4.2)$$

Descriptions of the failure type and exposure criteria evaluation procedures follow.

a. Failure Type - Failure type is a measure of the way in which a bridge fails. When evaluating this parameter, the actual vulnerability of a bridge to the specific failure mode is not considered and it is assumed that a failure has or will take place. The task of the rating engineer is to decide what the failure would look like. That is, will it be a sudden and complete collapse with potentially catastrophic consequences or will it be a partial or localized failure that may or may not affect the serviceability of the structure.

Three failure types have been defined and are shown in Table 4.4.

Failures due to seismic forces generally will involve movement of the substructures, such as tilting of a pier or settlement of an abutment, which results in a loss of support

or shifting of the superstructure. Shear and flexural failures in the substructures is another possible failure mode. To evaluate the type of failure a bridge is prone to, both the superstructure and the substructure configurations must be considered. For example, a simply supported, multigirder bridge is prone to catastrophic failure caused by large relative movements at the expansion joints and loss of support due to insufficient seat widths. On the other hand, a continuous multigirder bridge is unlikely to collapse in this way, but may suffer damage to the piers due to higher shear forces.

Table 4.4 Failure type definitions

Catastrophic - The structure is vulnerable to a sudden and complete collapse of a superstructure span or spans. This failure may be the result of a partial or total failure of either the superstructure or the substructure. A failure of this type would endanger the lives of those on or under the structure.

Partial Collapse - The structure is vulnerable to major deformation or discontinuities of a span (which would result in loss of service to traffic on or under the bridge). This failure may be the result of tipping or tilting of the substructure causing deformations in the superstructure. A failure of this type may endanger the lives of some of those crossing or under the structure.

Structural Damage - The structure is vulnerable to localized failures. This failure may be the result of excessive deformation or cracking in the primary superstructure or substructure members of the bridge. A failure of this type may be unnoticed by the traveling public but would require repair once it is discovered.

In some instances it may be necessary to obtain additional assistance from experts in other fields, such as geotechnical engineers.

Some factors which should be considered to evaluate the failure type are listed below. Combinations of these and other factors will determine the potential failure type of a structure.

- Redundancy of the Superstructure (internally and externally)
- Simple span vs Continuous spans
- Bridge type
- Span length
- Support conditions
- Abutments and Piers:

Type	Size
Height	Foundations
Bearing types	Seat widths

Rating scores are assigned for the different failure types, as shown in Table 4.5. These scores are used in Equation (4.2) to determine the consequence of failure score.

Table 4.5 Failure type rating scores

Failure Type	Score
Catastrophic	5
Partial Collapse	3
Structural Damage	1

- b. Exposure** - The exposure parameter is a measure of the affect that a failure of a structure will have on the users of the bridge and the highway network. The exposure score is determined on the basis of the traffic volume on the bridge and the functional classification of the highway carried by the bridge. The score is determined as shown in Equation (4.3). This score is used in Equation (4.2) to determine the consequence score.

$$\text{Exposure Score} = \text{Traffic Volume Score} + \text{Functional Classification Score} \quad (4.3)$$

Rating scores for traffic and functional classification are assigned as shown in Table 4.6. These scores are used in Equation (4.3).

Table 4.6 Exposure rating scores

Traffic Volume		Functional Classification	
AADT	Score	Functional Classification	Score
> 25,000	2	Interstate & Freeway	3
4,000 - 25,000	1	Arterial	2
< 4,000	0	Collector	1
		Local Road & Below	0

The functional classifications are based on the definitions listed in the BIIS manual [1] for the feature carried by the structure.

RC _____ BIN _____ DATE _____
 CARRIED _____ NAME _____
 CROSSED _____

LIKELIHOOD SCORE:

Vulnerability Class

High = 10
 Medium = 6
 Low = 2
 Not Vulnerable = 0

CONSEQUENCE SCORE:

Failure Type

Catastrophic = 5
 Partial Collapse = 3
 Structural Damage = 1

EXPOSURE SCORE:

Traffic Volume

> 25,000 AADT = 2
 4,000 - 25,000 AADT = 1
 < 4,000 AADT = 0

Functional Classification Score

Interstate & Freeway = 3
 Arterial = 2
 Collector = 1
 Local Road & Below = 0

TOTAL = _____

VULNERABILITY RATING :

Scoring Range Rating

> 15 1
 13 - 16 2
 9 - 14 3
 < 15 4
 < 9 5
 N / A 6

Figure 4.2 - Vulnerability Rating Summary Sheet

SECTION 5 - REFERENCES

1. "Bridge Inventory and Inspection Systems", Manual, New York State Department of Transportation, Structures Design and Construction Division, 1990, and Amendments 1991, 220 pp.
2. "Seismic Retrofitting Manual for Highway Bridges", Federal Highway Administration, Report FHWA-RD-94-052, 1995, 309 pp.
3. "A Policy on Bridge Safety Assurance", New York State Department of Transportation, 1992.
4. "Seismic Design References", California State Department of Transportation, Division of Structures, 1990.
5. "Seismic Design", Standard Specifications for Highway Bridges, Division I-A, 15th Ed, American Association State Highway and Transportation Officials, 1996, and Interims 1997, 1998.
6. "Seismic Retrofitting Guidelines for Highway Bridges, Federal Highway Administration Report, FHWA/RD-83/007, 1983.
7. "Uniform Code of Bridge Inspection", NYS Department of Transportation, October 1989
8. New York State Standard Specifications for Highway Bridges, NYS Department of Transportation, June 1999.

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APPENDIX A

FUNCTIONAL IMPORTANCE (BRIDGE CRITICALITY)

SPC ‘A’ and SPC ‘B’ Bridges:

For guidance in determining Bridge Criticality, please refer to Article 6A.4 in Division 1A of the NYSDOT Standard Specifications for Highway Bridges [8].

NYC (Downstate) Area Bridges:

For the NYC (Downstate) Area, a “critical” bridge is defined in Table 6B.3-1 in Division 1A of the NYSDOT Standard Specifications for Highway Bridges [8]. Additional requirements for critical bridges are included in Article 6B.3 in Division 1A of the NYSDOT Standard Specifications.

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APPENDIX B

NEW YORK STATE SEISMIC PERFORMANCE CATEGORIES

SPC 'A'

Region 2 - All Counties
Region 3 - All Counties
Region 4
(Wayne, Ontario and
Livingston Counties)
Region 5
(Cattaraugus and Chautauqua
Counties)
Region 6 - All Counties
Region 7
(Jefferson and Lewis Counties)
Region 9
(Broome, Chenango, Otsego
and Delaware Counties)

SPC 'B'

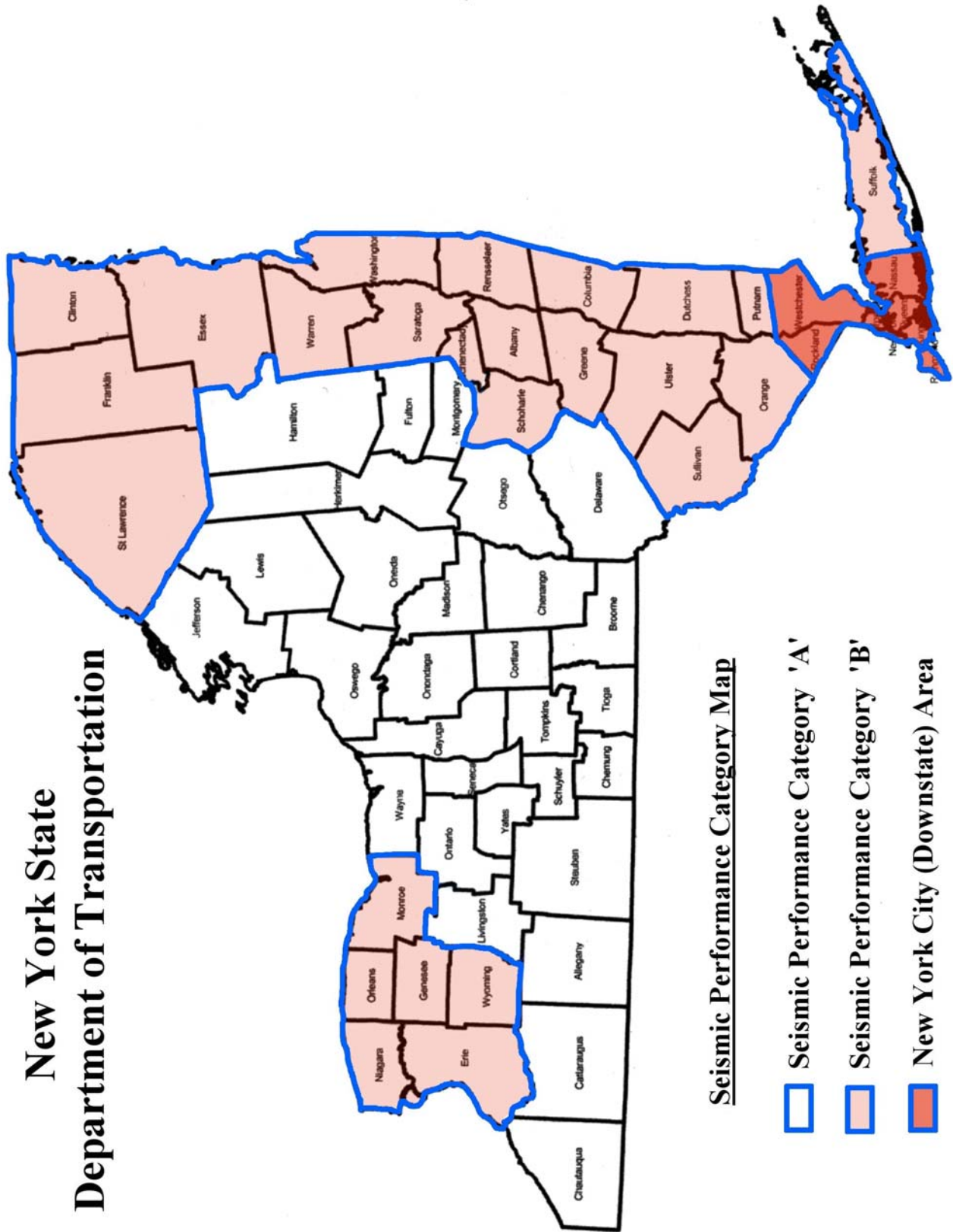
Region 1 - All Counties
Region 4
(Genesee, Orleans, Monroe
and Wyoming Counties)
Region 5
(Erie and Niagara Counties)
Region 7
(St. Lawrence, Franklin
and Clinton Counties)
Region 8
(Columbia, Dutchess, Putnam,
Orange and Ulster Counties)
Region 9
(Schoharie and Sullivan
Counties)
Region 10
(Suffolk County)

NEW YORK CITY (DOWNSTATE) AREA

Region 8
(Rockland and Westchester Counties)
Region 10
(Nassau County)
Region 11 - All Counties

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New York State Department of Transportation



Seismic Performance Category Map

- Seismic Performance Category 'A'
- Seismic Performance Category 'B'
- New York City (Downstate) Area

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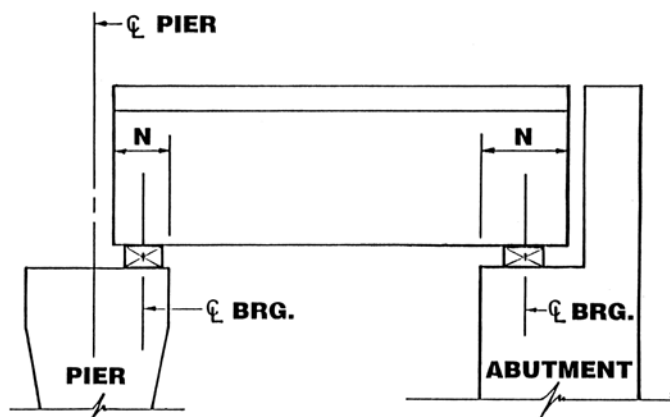
APPENDIX C

VULNERABILITY RATING SCALE

1. **SAFETY PROGRAM WATCH** - This rating designates a vulnerability to failure resulting from loads or events that may occur in the next few years. Corrective or mitigating action, enhanced inspection or other appropriate safety action, such as placing on a flood watch, shall be taken. If corrective or mitigating action is not immediately taken, placing the bridge on the current 5-Year Capital Program along with appropriate interim safety action such as continued monitoring or traffic restrictions shall be considered.
2. **SAFETY PROGRAM ALERT** - This rating designates a vulnerability to failure resulting from loads or events that may occur, but are not likely in the next few years. Remedial work to reduce the vulnerability or enhanced monitoring is not an immediate priority, but may be needed in the near future. Placing the bridge on the Capital Program should be considered.
3. **CAPITAL PROGRAM ACTION** - This rating designates a vulnerability to failure resulting from extreme loads or events that are possible but not likely. This risk can be tolerated until a normal capital construction project can be implemented.
4. **INSPECTION PROGRAM ACTION** - This rating designates a vulnerability to failure presenting minimal risk providing that anticipated conditions or loads on the structure do not change. Unexpected failure can be avoided during the remaining life of the structure by performing the normal scheduled bridge inspections with attention to factors influencing the vulnerability of the structure.
5. **NO ACTION** - This rating designates a vulnerability to failure which is less than or equal to the vulnerability of a structure built to the current design standards. Likelihood of failure is remote.
6. **NOT APPLICABLE** - This rating designates there is no exposure to a specific type of vulnerability.

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APPENDIX D



Minimum support length (N) in the longitudinal direction should be measured perpendicular from the end of the centerline of the girder/beam to the edge of the bridge seat. Minimum support length (N) in the transverse direction should be measured perpendicular to the centerline of the girder/beam.

$$N = (8 + 0.02L + 0.08H) (1 + 0.000125S^2) \quad (\text{inches}) \quad \text{Equation A}$$

or

$$N = (203 + 1.67L + 6.66H) (1 + 0.000125S^2) \quad (\text{mm}) \quad \text{Equation B}$$

where

L = length of continuous bridge deck, in feet for Eq. A or meters for Eq. B

S = angle of skew of support in degrees, measured from a line normal to the span.

and H is given by one of the following:

for abutments, H is the average height, in feet for Eq. A or meters for Eq. B, of columns supporting the bridge deck to the next expansion joint. H = 0 for single span bridges.

for columns and or piers, H is the column or pier height, from the top of footing to the top of pier/pedestal, in feet for Eq. A or meters for Eq. B .

for hinges within a span, H is the average height of the adjacent two columns or piers in feet for Eq. A or meters for Eq. B .

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